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ORIGINAL ARTICLES.

On the Structure and Mode of Occurrence of *Scolithus linearis* (Haldeman) in the Cambrian Quartzites of the North-West Highlands.

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(PLATES IV–VII.)

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I. INTRODUCTION AND HISTORICAL ACCOUNT.

IT is some thirty years ago and about ten years after the mapping of this area by the officers of the Geological Survey that one of the present writers ascended Quinaig at Inchnadamph and saw for the first time the so-called "Pipe-rock" which caps the summit of that mountain. Here one can walk over the exposed surfaces of the quartzite and it is impossible not to observe the curiously spotted or pitted surfaces of the white slabs which, in many places, look like nothing so much as the soles of a labourer's shoe covered with projecting hobnails (see Plate IV, Fig. 1).

Since then we have paid repeated visits to the North-West Highlands, and on each return we have been increasingly puzzled by many of the phenomena exhibited by the piped quartzite. On our return last year a flood of light was thrown upon a peculiarity connected with those pipes, by the discovery of certain boulders in a wall at Rispond, 4 miles east of Durness. This is the subject of the present paper.

The first reference we can find as to the occurrence of this pipe-rock was made by Macculloch (1) [1] in the year 1814. As the reference

[1] Figures in parentheses refer to references at end of paper.

does not seem to be generally known, and since it is a clear and concise description of the tubes, as well as a recognition of their annelid origin, we think it well to quote it in full here.

In speaking of the quartz rock of the Assynt district, Macculloch observes the presence of imbedded cylindrical bodies which they occasionally exhibit. We may previously remark that this rock has a frequent tendency to break into rectangular masses similar to those which occur in many block sandstones.

"In these fragments the weathered surfaces present on the upper part or that which forms the plane of the stratification a number of circular protuberant spots apparently arising from the circumstance of their hardness being greater than that of the general mass, the lateral plane of the same fragments exhibits, on the other hand, a similar number of corresponding cylinders of a hardness in the same way superior to that of the surrounding parts. If I might venture on a comparison, as vulgar as it is explanatory of this appearance, I would compare it to the two sections of a piece of larded meat. I may further add that in these cases the cylindrical bodies are of a much whiter colour as well as of a more compact texture than the rest of the stone and that on breaking the stone to examine further into this structure the whole disappears and a uniformity of texture is exhibited throughout.

This peculiar appearance is familiar to all those who are conversant in the varieties of floetz sandstone, and the superior hardness of the cylindrical or vermicular bodies in the sandstones of this class is equally notorious as they often continue to project for the space of even half an inch beyond the decomposing rock, appearing as if nails had been driven into it. The coast of Fife about Burntisland [1] affords excellent examples of this fact. I know not if any attempt has been made to explain this circumstance in the floetz sandstones, but it probably arises from the remains of some animal or other marine worm. Whatever it be, it is sufficient to establish the similarity in the original structure of this mountain rock with that of the present floetz formation."

The next reference we can find is that made by Cunningham (2) in 1841. Notwithstanding Macculloch's clear and definite statement regarding the nature and origin of those cylinders, his association of them with the worm burrows in the Carboniferous rocks of the Firth of Forth, and his ascription to them of an annelid origin, Cunningham seems to have remained unconvinced. He tells us that he has investigated them with care, but can only see in them such concretionary structures as can be seen in all strata, and which have been formed during the process of consolidation.

In support of this he refers to the perfectly undefined characters

[1] We have often wondered as to the exact locality here mentioned by Macculloch. We have long been familiar with the fine display of worm burrows and castings in the sandstone of the railway cutting.

of bodies except where they have been exposed to the action of the weather and that they do not show any definite form when the quartzite is fractured at right angles to the bedding, from which he concludes that they cannot be the relics of either plants or animals. From this statement it would appear that he had only observed the examples preserved in the pure white quartzite and was unacquainted with those in the pink or reddish quartzite in which the matrix is stained with iron, and in which the cylindrical and trumpet-shaped burrows present very distinct forms and structures. He makes a still further statement to the effect that he could trace a most gradual transition between the supposed organic remains and the smallest quartz concretions, evincing consequently that they are only to be considered as a modification of such.

Throughout his different papers Nicol (3) often refers to the various outcrops of the piped quartzite between Assynt and Loch Eireboll, and incidentally we may note that he points out in support of his views as to the inversion and overthrusting of the rocks, that on Arnaboll Hill (east side of Loch Eireboll) the openings of the annelid tubes and the ripple marks which are regularly found on the upper surface of the beds are here on the lower faces, showing that there has been a complete reversal of the strata. This is a striking example of the prescience of that distinguished geologist.

The quartzite and limestones have in this region been brought in by the Arnaboll Thrust and repeated over and over again by minor thrusts. Along the soles of these thrust-planes the tubes have been drawn out into ribbons parallel to the shearing of the quartzites. Nicol (4) suggests that in the quartzite period organic life undoubtedly existed. Two score years ago Macculloch pointed out curious conical hollows ending in long pipe-like bodies, these he described as worm-holes, the prototypes of those seen on the shore where the lobworm sinks into the sand left dry by the retiring tide.

Of the quartzite Heddle (5) still further writes, " this quartzite contains the characteristic ' worm holes ' much more sparsely than do the upper beds."

" The quartzite is frequently highly stained with ferruginous matters, which give it a purplish-brown tint. The colouring matter of both quartzite and conglomerate has been termed ferrite, but as this was the name given by the late Wallace Young (6) to a magnesium pseudomorph olivine its use here is inadmissable. Where the rock is deeply stained the worm holes are more or less white. It is also to be observed that in many cases the sand grains which fill these holes are smaller than those of the general mass of the rock."

A number of years ago one of the present authors (7) described the occurrence in the upper Carboniferous limestones of the Glasgow district of a series of thin alternating beds of flaggy sandstones and shales containing numerous annelid burrows as follows :—

They occur in greatest numbers towards the top of each layer of sandstone, and die out altogether near the bottom of the thicker

bands. This would seem to indicate that the annelids lived only during the period when the mud now represented by the shale was being laid down, and that when the change of conditions again brought back the sand deposit, they either died off, or were forced to migrate to a more suitable locality.

The burrows are never found in the sandstone bands solely, their trumpet-shaped mouths invariably opening into the shale through which they pass vertically down into the sandstone and not a single trace of them can be seen either in the sandstones above or in the flagstone group below. The short space of time in which these organisms returned to their former quarters after the renewal of favourable conditions is shown in some of the thicker beds of sandstone, where rows of burrows occur without apparently any intervening deposit of shale. On closer inspection, however, it will be observed that extremely fine layers of shale—not thicker than a sheet of tissue paper—actually do exist (Plate V, Fig. 1).

Living during the periods represented by the layers of shale, like their modern congeners on our present shores, the annelids had the power of burrowing rapidly through the sand and mud and extracting the contained organic matter, much as the earthworm does in the upper soil. They passed the finer argillaceous material through their bodies in search of food material, e.g. diatoms, small animals and animal remains, the undigested matter being either voided into the burrow behind the animal or on the surface in the form of casts with which certain of the beds are covered. It is interesting to note than in connection with the history (8) of these annelids the lower members of this Carboniferous section are said to contain comparatively few burrows, which gradually increase in number upwards till the flagstones become literally crowded with them, while above this they begin to decrease till they gradually die out. In the flagstone quarry the burrows are certainly fewer in the lower beds and increase in number in the higher, but we have not been able to notice their dying out again, as the annelid beds are suddenly truncated by a strong line of erosion.

This summer while living at Rispond, on examining a wall largely composed of boulders of Lewisian gneiss and blocks of purplish quartz our eyes were suddenly arrested by a number of quartzite boulders in which all the phenomena just described as seen in the Carboniferous rocks of the Glasgow district were distinctly repeated, the whole phenomena being exactly homologous—as can be seen by an examination of Plate IV, Fig. 2.

As this phenomena has not, so far as we are aware, yet been described in connection with the pipe-rock, the object of this paper is then to institute a comparison between the phenomena exhibited in the Cambrian burrows on the one hand and the Carboniferous on the other, and also to see what light has been shed upon these ancient burrows by the most recent researches into the burrowing of errant annelids at the present day.

II. The Formation of Recent Annelid Burrows.

Let us now consider the manner in which such a living errant annelid, such as *Arenicola marina*, forms its burrow.

Ashworth (9) has pointed out that specimens of *Arenicola marina* taken in the littoral zone are generally found to form U-shaped burrows which average 180 to 230 mm. in length. On the other hand specimens from the upper part of the laminarian zone, only readily obtained at low tides, are found in vertical or L-shaped burrows. In seeking their food the sand is passed through the alimentary canal, and ejected from the intestine by the anus, forming a rounded or trochoid heap of vermicular coils. These coiled castings of *Arenicola marina* are familiar objects on many of the sandy beaches round our shores.

As regards the habitat and habits of *Arenicola marina* we are again indebted to Professor Ashworth's valuable researches on this species of errant annelid. He points out that M. Bohn states that *Arenicola marina* leaves its burrow at night to swim in the sea. Also, that Professor Ehler records the swimming of an adult *Arenicola marina*, and the capture before sunrise of specimens (80–120 mm. long) in the surface tow net in shallow water off Heligoland.

Professor Ashworth has shown that in certain estuaries during flood time the water has a much less density than in the sea. He also points out that *Arenicola* adapts itself less readily than *Nereis* to estuarine conditions.

Referring to Ferronnière, he states that he found *Nereis diversicolor* much higher up the estuary of the Loire than *Arenicola marina*. In recent observations in the Firth of Forth, it has been shown that *Arenicola marina* occurs at a considerable distance up the estuary of the Firth even as far up as a mile above Kincardine, where the water is subject to periodical freshets. It is further pointed out that these individuals which live higher up the estuary than Kincardine will be subject to water of much lower density, and when the flooding is high and prolonged will be living in practically fresh water.

It is suggested that at those times the worms may burrow much more deeply into the mud in which there will be an increasing salinity of the water.

The mode of occurrence of Arenicolides in the Carboniferous rocks of the Glasgow district distinctly points to an estuarine habitat with the sea probably not far distant, the estuary being subject to periodic floods, represented by the layers of shale (Plate V, Fig. 2).

The relationships of the annelid beds to the massive sandstones lying above or below them clearly show this local nature of the deposit, as they rapidly thin out in all directions till they finally disappear and the overlying and underlying beds come together, without any intervening annelid beds.

Owing to the lack of accurate data regarding the factors limiting

the habitat of *Arenicola marina* one of us (10) performed certain experiments with the worms in question to this end.

It is known from our own observations and those of Ferronnière (11) that *Arenicola marina* does not live in pure sand, though they will burrow into it, nor in pure fresh mud but in a mixture of sand and mud. As has already been pointed out, *Arenicola* can and does occur in water of various density. These, of course, are general statements merely and do not throw any light on the problem of the presence or absence of worm tubes in the Cambrian quartzite and Carboniferous sandstones.

The experiments were carried out, therefore, to find (*a*) why the worm tubes were always absent from the pure red quartzite, i.e. quartzite containing no horizontal white lines of pure sand, (*b*) the minimum degree of salinity they could withstand.

Since the colouring matter of the quartzite was found to be amorphous ferric oxide, tests were carried out with this substance.

Worms of the species *Arenicola marina* were introduced into vessels containing a mixture of ferric oxide and sand. It was found that they refused to burrow if the sand contained 2 per cent of the oxide and would only burrow into sand containing 0·3 per cent of the oxide if the mixture were covered by a layer of pure sand. Since, however, the ferric oxide would not remain mixed with the sand under marine or estuarine conditions but would be stirred up and held in suspension by the water, it follows that its effect on the organisms under these conditions must be examined. Experiments on this subject showed that a very much smaller percentage (0·021 per cent) of the oxide was lethal. Numerous other finely divided substances were found to behave in a manner exactly similar to ferric oxide. From this it may justifiably be concluded that the worm pipes in the red quartzite extend downwards from the white layer of quartz because it was possible for the worms to live only when the pure sand formed a barrier which prevented the ferric oxide from getting into suspension.

In the case of the Carboniferous sandstone exactly the opposite must have been the case. There was nothing to hinder the worms from burrowing into the sandstone from any surface.

The deposition of a layer of fine mud, however, would tend to put an end to their activities and, although the result as far as appearance goes may be the same the cause is completely the opposite. One other interesting fact visible in the photograph may be pointed out in support of this. It will be noticed that in the Carboniferous rocks, wherever a tube begins it does not continue through the layer of shale (mud) lying next below it, while in the case of the Cambrian quartzite the tubes may run through several white bands.

Although not directly bearing on this paper it may be useful to give the results obtained from the second group of experiments. In 50 per cent sea-water the worms behaved in a perfectly normal manner, but in 30 per cent sea-water they became turgid and

ceased to attempt to burrow. From these figures it may be seen that the limiting density is somewhere between 30 per cent and 50 per cent.

III. Subdivisions of the Piped Quartzite.

It is unnecessary that we should here enter into a detailed description of the Cambrian quartzites as a whole; sufficient be it to say that they have been divided by the officers of the Geological Survey (12) into two zones, an upper and a lower. The upper containing the worm tubes has been defined as follows :—

Fine-grained quartzites perforated by vertical worm casts and burrows becoming more numerous towards the top of the zone (" Pipe-rock " of previous authors) and has been still further divided into the following five sub-zones :—

Sub-zone 1.—Characterized by small pipes about an eighth of an inch in diameter passing upwards and opening in small cup-shaped hollows.

Sub-zone 2. The ordinary pipes are larger, often reaching half an inch in diameter while the underlying type of burrows has disappeared.

Sub-zone 3. The burrows are trumpet-shaped, with openings sometimes measuring 2 inches across. Peach (12) has pointed out that the cylinder can be seen to stand up a little into the cup (see Plate VI, Fig. 1) and that the layers of quartzite are attenuated and bent downwards, where they approach the cylinder. From this phenomenon Peach concluded that the worms must have been abundantly supplied with chaetae. The tubes in this zone often present on the surface a cone-within-cone structure which led some of the previous observers to look upon them as some primitive form of *Orthoceras*.

Sub-zone 4. Pipes similar to those of the lower zones but are much more numerous and conspicuous.

Sub-zone 5. Pipes are somewhat larger than the foregoing but are otherwise of the ordinary type. The coloured matrix shows discoloration round the " pipe " similar to that found in the sand round the tubes of present day lugworms.

IV. Description of the Burrows.

Microscopically, the annelid burrows in the quartzite present various types of form as has been described in a previous section.

Where the body of the quartzite is pure white in colour the annelid tubes are not easily discernible in longitudinal sections, and can only be recognized by the knob-like projections when the quartzite cylinders are harder than the surrounding matrix or in little pit-like depressions when it is softer. But when the matrix is tinged with a pinkish colour (ferric oxide) the whole cylinder is

readily distinguishable as in a specimen from the west side of the Kyle of Durness [1] (Plate VI, Fig. 2).

In Sub-zone 3 the trumpet-shaped openings are well displayed as is also the bending down of the layer of quartzite where they approach the cylinder. On the surface of the beds the peculiar cone in cone-like structure described by Peach is also quite apparent. The origin of this is not quite apparent and we have not been able to offer any adequate explanation of the phenomenon. In this slab can also be seen (mixed with the trumpet-shaped burrows) the simpler cylinders of the lower sub-zones, on comparing the burrows in the Cambrian pipe-rock of Durness with those of the Carboniferous sandstones of the Glasgow district the parallelism becomes strikingly apparent. They present the same cylindrical-shaped burrows opening on the surface into trumpet-shaped hollows (Plate V, Fig. 1).

In the Carboniferous sandstones the burrows are filled in with shale originally mud, and stand out distinctly against the whole sandstone in which they are formed. But the most striking feature is the fact (see Plate V, Fig. 1) that the burrows in the Carboniferous sandstone invariably open by their trumpet-shaped mouths into the layer of shale, and are never found to start from any part of the intervening sandstone beds. They may appear to do so, but closer inspection reveals the fact that they open from a layer of shale which may be no thicker than a sheet of tissue paper. Now the same phenomenon is presented by the blocks found in the wall at Rispond (Plate IV, Fig. 2).

An inspection of the photograph shows that the same phenomena are exhibited in the Cambrian Quartzites where at least five distinct alternations of purplish and white quartzite can be counted, there being also a sixth at the base of the block. The same trumpet-shaped and cylindrical burrows are filled in with pure white quartz grains, which are sometimes smaller in size than those forming the purplish grained mass. A careful examination of these burrows shows that they vary considerably in the complexity of their structure.

Many of them are simple cylindrical tubes as already stated, but others show a distinct triaxeal structure, both when seen on the surface and in longitudinal section. In the more complex types the structure is crater-like in appearance, having an outside wall, a median hollow and a central knob, the whole forming the cone in cone-like structure just referred to.

V. Chemical Analysis.

Qualitative analysis of the Pipe-rock showed it to be composed of quartz and iron. The latter in the form of amorphous ferric oxide.

[1] Higher pipe zone where the quartzite sinks below the limestone of Balnakiel Bay.

1

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Fig. 1.—Piped Quartzite showing cone-in-cone structure. From the Kyle of Durness.

Fig. 2.—Block of Piped Rock, Rispond.

[To face p. 56.

1

2

Fig. 1.—Carboniferous Annelid Tubes.

Fig. 2.—Carboniferous Annelid Tubes, Giffnock. 50 alternating beds of Shale and Sandstone with worm tubes.

Fig. 1.—Annelid Tubes, Carboniferous, showing trumpet-shaped burrows.

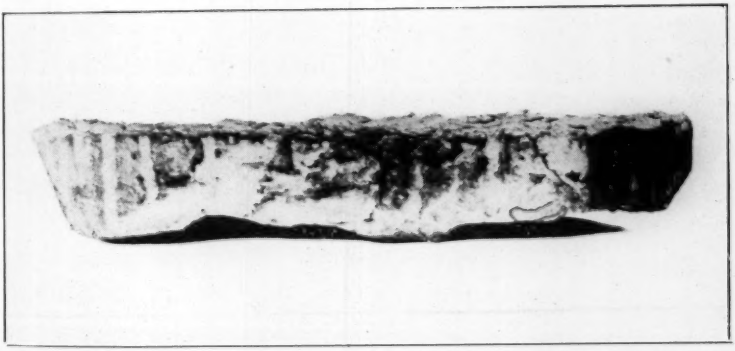
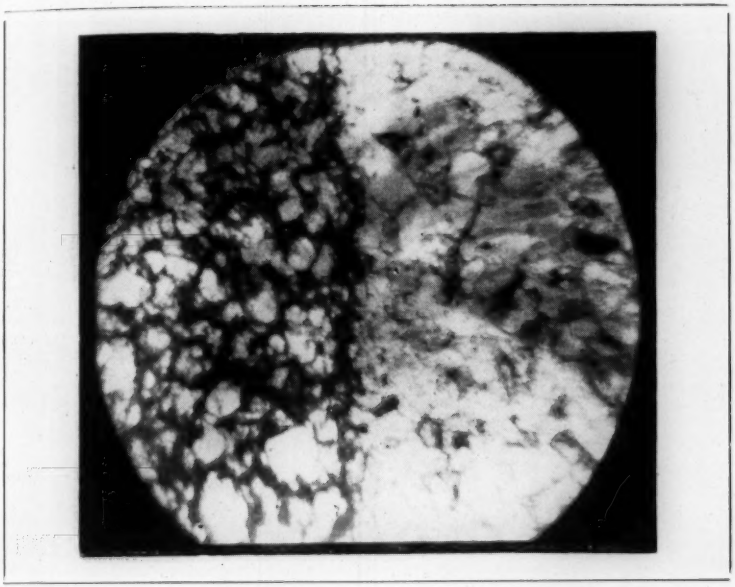
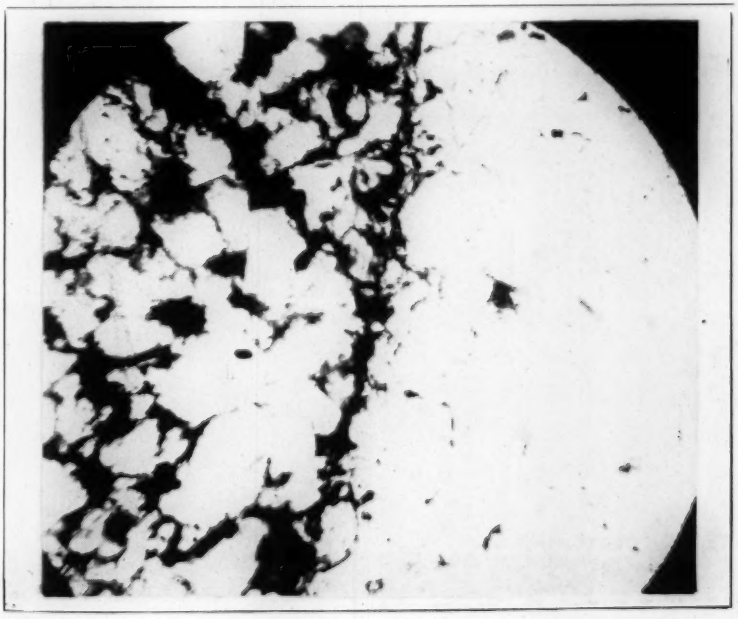


Fig. 2.—Longitudinal Section of Fig. 1 (Plate IV).



Unpiped rock. | Worm pipe.

FIG. 1.—SECTION OF PIPE-ROCK SHOWING THE LARGE PROPORTION OF IRON-OXIDE IN THE UNPIPED PART AS COMPARED WITH THAT IN THE WORM PIPE. MAG. × 35 LIN.



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Unpiped rock. Edge of pipe. Worm pipe.

FIG. 2.—VERTICAL SECTION SHOWING RELATIVE AMOUNTS OF IRON-OXIDE IN EACH PART. MAG. × 56 LIN.

Quantitative analysis of a number of specimens showed a great range in the amounts of ferric oxide present. This fluctuation in amounts may be explained by the fact that it is almost impossible to get a piece of the matrix sufficiently large which is not riddled with worm tubes, with their (almost) iron free sand. However, it was found that the maximum ferric oxide content was about 10 per cent ranging down to about 1 per cent and more than probably striking an average at about 3 per cent. This is made clear in the microphotographs (Plate VII, Fig. 1) showing much more ferric oxide (the dark mass among the clear quartz grains) than Plate VII, Fig. 2.

Both of these Figures show very clearly the great difference between the "pipe" and the matrix and the hard line of demarcation which exists along the wall of the pipe.

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The Moon and Radioactivity.

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IN a study of the surface features of our satellite one is immediately struck by the remarkable sharpness and freshness which most of those features exhibit. Further, one is impressed by the fact that evidences of compressive action are in the minority, whereas the moon's crust shows clearly innumerable clefts, rifts, and fractures pointing to an extensional tendency of its outer envelope. This is hardly in accordance with our ideas of the appearance of a sphere which has lost all its heat; everywhere it should show signs of intense contraction, and arcuate mountain ranges should be more frequent than upon the face of the earth.

It is now generally accepted that the moon must have cooled to something like its present condition long before the earth came to the state in which its igneous fluid mass was crusted over. According to Dr. R. H. Rastall [1] the moon is very probably the missing

[1] "The Continents and the Origin of the Moon," *Nature*, 2nd May, 1925.

two-thirds of the earth's sialsphere, which in the liquid state was stripped off by some form of tidal resonance. A certain amount of sima was stripped off at the same time, giving the moon its density of 3·46. (Density of sial, about 2·7.) Support is lent to this view by the recent investigations made by Dr. F. E. Wright[1] on the optical course of the moon's radiation. He states that " results clearly indicate that at the surface of the moon, no dark rocks, low in silica, nor iron, nor obsidians are exposed in appreciable amounts; but light-coloured rocks, high in silica and powders of transparent substances, are possible ". In other words, the moon's surface is predominantly of sial.

Now it seems highly improbable that the surface features of the moon would be so well preserved had they been formed at that remote period before the earth had obtained a solid crust. It is true that the ordinary agents of erosion and degradation are absent on the moon, but there still remain two destructive forces to be reckoned with; forces which surely should have obliterated or dulled the trace of finer markings in the immense period of time at their disposal. The first of these is differential expansion and contraction in the rocks, aided by gravity, and rendered far more potent than on the earth by the tremendous temperature range and the abruptness of thermal changes experienced on the atmosphereless moon. This force should operate to cause exfoliation of every exposed rock surface, causing a slow but inevitable degradation of relief. The rock screes would creep downwards through expansion and contraction. The absence of water and organic matter would prevent cementation of the talus, and movement would continue until a low angle was reached. It should be noted that the smaller gravity value on the moon is offset by the fact that this reduces friction, so the capacity of loose material for downward motion is not thereby affected.

The fact that this temperature change now occurs but once in every fourteen days does not diminish the value of the argument. For if the moon's features were formed before the earth's crust had cooled, these features were then more often exposed to the temperature changes, owing to the moon's then greater rapidity of rotation. Subjection to this temperature range, even if only once every fourteen days, throughout the immense period which has elapsed since pre-Archeozoic times, must surely have operated to degrade the moon's features in a marked degree. Yet we see that this is not the case, and an explanation must be sought.

The second destructional force likely to obliterate the moon's sharp relief is the continuous bombardment of meteors and meteorites to which it is no doubt subjected. The moon being destitute of any protective gaseous envelope, all meteors entering its gravitative field will come into contact with its surface. The impact of these bodies will by their shock, and also by hitting

[1] Carnegie Institution of Washington, Year Book, No. 26, 1926–7.

screes directly, greatly accelerate the downward motion of rock particles.

Again, the moon exhibits on its surface a colour-range between the dark lavas of the "seas" or maria and the dazzling white ray-systems which surround the largest craters or vulcanoids. One cannot believe that this gradation in colouring could have persisted since the moon's formation, under an incessant hail of meteors. For if a meteor's force of impact be sufficient, its constituents will be immediately volatilized by the resultant heat. The meteoric material will thus be scattered, but will soon settle down upon the crust. In time the whole surface of the satellite will be covered by a homogeneous layer of meteoric dust which will give the lunar features a uniform hue. If on the other hand the meteoric mass merely pits the surface without being volatilized, the effect will be to change the colour for the area of that pit. Continuous pitting of the surface will ultimately reduce the whole surface to the same hue.

Against this it may be said that the vast majority of meteorites will fail to reach the face of the moon visible to us, owing to the earth's superior gravitative attraction, and that most meteorites will fall upon the hidden face. But again it must be remembered that the moon has not always rotated at its present speed, and that throughout earlier ages it exposed every part of its surface equally to meteoric attack. The immense period during which its rotation was more rapid than now should surely have been sufficient for meteoric attack to have dulled or entirely obliterated any colour gradation. An atmospheric envelope during the moon's early history would have shielded it from direct attack, but would have effected the deposition on the surface of a layer of meteoric dust which would mask the colour gradations. When the atmosphere had dispersed, the masking would be continued by either of the methods outlined above. And yet this diversity of hue persists to-day.

It may be urged that the moon is not subjected to meteoric attack, since meteorites are held by some to be volcanic material ejected from the earth at an earlier stage in its history. Or it may be argued that it is possible that the earth and moon have but recently reached a part of space where meteors exist, and that therefore there has not yet been time for the falling bodies to produce any marked effect upon the moon's surface.

However, even if one or other of these arguments be accepted to account for the still-existing diversity of colour evident on the moon there still remain to be explained (*a*) why our satellite shows signs of expansion rather than contraction, (*b*) why its features are so clear in spite of degradation due to differential contraction and expansion of its surface materials.

Question (*b*) induces the idea that features of the moon are clear and sharp because they have not long been exposed to the degradational forces; in other words that they are of comparatively recent

origin. Both questions seem to be satisfactorily solved when one applies to the moon Professor Joly's [1] well-known theories of radioactivity, which seek to account for geological periodicities upon the earth.

We have accepted the assumption that the moon was originally derived from the outer layers of the earth. Therefore it must have the same radioactive constituents as our globe. Furthermore, radioactivity should be greater in the moon than in the earth, since the former contains a larger proportion of sial, and the lighter acidic rocks are more radioactive than the denser basic rocks. Density considerations lead us to expect that whereas the inner core of the moon is sima, a large part of its volume down to a very considerable depth beneath its crust will be of sial. Joly has shown that in the earth, heat accumulations due to radioactivity beneath the continental blocks will escape when the substratum is liquefied, and the heated areas are brought beneath the thin sima ocean-beds, through the crust being rotated over the liquid substratum by tidal drag. He has also shown that a continuous belt of land around the equatorial regions of the globe would be an unstable arrangement, for then no amount of slipping of the crust over the molten interior would provide any means of escape for the heat. The continuous belt would ultimately be broken up by melting.

On the moon, however, not only is there a continuous belt of sial around the equatorial regions, but the whole surface of the sphere consists of a thick crust of that material. Obviously heat accumulated within the interior of the moon due to radioactivity, cannot escape by the means advocated for its dispersion in the earth. Only a period of cataclysmic vulcanicity marked by violent eruptions, rending of the crust, and outpouring of lavas can release the pent-up heat. It is to such a revolution that the surface features of the moon can be ascribed, their state of excellent preservation pointing to a comparatively recent date of formation.

An examination of the moon's features lends very substantial support to this conception. Everywhere there are traces of exceptionally violent eruption, craters occupying a very large proportion of the surface. That the largest craters appear to have been formed first, confirms the expectation that the initial outburst of the compressed lavas would be of great violence. Concurrently the great rifts, clefts, and fractures were formed, as the thin skin of unmelted crust was extended to cover the now greater volume of the sphere. For, as heat accumulated within the crust, so would the constituents of the interior tend to become liquefied and less dense. Only the intense pressure would keep them from liquefaction. However, a time would come when the crust was so far weakened from beneath as to be no longer strong enough to resist the internal pressure.

[1] *The Surface-History of the Earth*, by John Joly. Oxford University Press, 1925.

Once lava had pierced the crust, pressure within would be lowered and rapid liquefaction and expansion would ensue. The volume of the moon would be increased and lava would rise in the innumerable fractures caused upon the crust. Where the fractures were but comparatively narrow, the lavas would not pour out upon the surface, for the radiation of heat upon the atmosphereless moon must be exceedingly rapid. Accordingly, in the narrow fissures the lava congealed before it could flood the surface. Further evidence of internal expansion is seen in the linear arrangement of many groups of small vulcanoids, which mark lines of fracture in the extended crust. A fine example of this is the line of craterlets over two hundred miles long between the vulcanoids Catherina and Abulfeda.

The formation of the lunar "seas" or maria next claims our attention. These features occupy a third of the moon's visible surface, and it is a remarkable fact that none of them cross the limb or "edge" of the moon. Most observers are agreed that the maria are out-pourings of lava, but a comparatively thin layer upon the moon's surface. Craters are relatively rare in these areas, owing no doubt to the fact that all but the highest of them would be covered in the lava-flow. That the formation of the maria occurred after the craters appeared, is proved by the fact that in certain places around the margins of the maria, craters have had parts of their walls melted away by the subsequent lava-sheet.

It must be remembered that, the substratum now being liquefied, there will be very considerable tidal bulges, due to the earth's attraction, tending to form beneath the crust. If the events of which we are speaking occurred so recently as to leave their traces undimmed, then it is justifiable to assume that at that comparatively recent date our satellite had reached its present rate of rotation, and then, as now, presented but one face to the earth. Beneath the face turned towards the earth it would continually be "high-tide", and a similar condition would obtain on the further side of the moon. Beneath these two opposed surfaces the tidal forces would exert pressure on the crust in an attempt to deform it to accommodate the two tidal swellings. On these two surfaces, at certain areas already weakened by fissuring as described above, the molten substratum would break through the thin crust and spread itself out in great lava-flows, the maria. This theory supposes the existence of maria on the hidden face, and explains why none of these features cross the limb of the moon. The limb would not be subjected to distortional tidal forces which act only parallel to a line joining the centres of the moon and earth.

One cannot expect a perfectly ordered gradation in intensity of fracturing of the crust and consequent extrusion of the maria, spreading outwards from a region of most marked fracture at the centre to areas of least marked fracture at the limb. This would only occur in a crust of perfectly homogeneous composition, uniform

thickness, and unvarying strength. The moon's crust was evidently less resistant to strain in some places than in others: for example, where the radioactive constituents were in a larger proportion than elsewhere, and by their greater heating melted the crust more effectively than in the surrounding parts. In these weakened portions of the crust fracturing and extrusion of the maria would be most strongly developed, even though these areas were not exactly coincident with the regions where tidal deformation was greatest. But certainly no extrusions occur anywhere on the limb, where tidal forces are parallel to the crust.

However, the distribution of the many fissures visible upon the moon corresponds fairly well with the conception of their formation by tidal stress beneath the crust. Shaler[1] observes that "those (fissures) which are in appearance sufficiently conspicuous to be mapped lie mostly in the central part of the visible surface, between the parallels of 30° north and south of the moon's equator, and within 30° east and 50° west of the central meridian. They are thus remarkably rare in high latitudes and apparently seldom near the east and west margins of the visible part of the sphere. This apparent feature of distribution may be due to the oblique view of these marginal fields." That this distribution is apparent rather than real as suggested by the previous sentence is unlikely, for surely if obliquity of view tends to render these features invisible, this effect should operate at equal distances from the central meridian, whereas this is not the case.

The terrace effect within many of the craters, due to stages in the sinking of the lava within them, may possibly be ascribed to lessening of internal pressure as a mare was poured out upon the moon's face. Then each terrace would mark a pause between the formation of maria, and the sudden drop in the lava would be produced by a reduction in pressure due to vast extrusions elsewhere.

The maria occupy the lower portions of the moon's surface. It is more likely that this is due to isostatic adjustment than that the lava confined itself to great basins. When the lava was extruded, the thin and fractured condition of the crust and the liquid condition of the substratum facilitated rapid isostatic equilibrium. The areas upon which the maria had been ejected would be rapidly depressed below the surrounding levels. In *The Face of the Earth*, vol. iv, Suess remarks that "the regular peripheral subsidence-fractures which surround the Mare Humorum at some distance from its margin, and in other similar examples show, however, that in some cases the circular subsidence extends beyond the surface of the lava". This is quite in agreement with isostatic theories. One does not expect the area of sinking to be sharply delineated by one continuous peripheral fault-scarp.

[1] N. S. Shaler, "A Comparison of the Features of the Earth and the Moon," *Smithsonian Contributions to Knowledge*, vol. xxxiv, 1903.

The moon having got rid of its heat by the means outlined, its surface is now a little too big for its cooling and contracting interior. Some of its internal mass has also been lost by extrusions of lava upon the surface. The fissures originally formed in the extension of the crust cannot now be closed again by the efforts of the outer envelope to contract with the shrinking substratum, for the fissures are filled with lava. Accordingly, the weakest parts of the surface are subjected to buckling and wrinkling, as the more rigid parts of the crust are thrust against them. We have seen that the maria occupy the most fractured portions of the crust, and the addition of at the most a few thousand feet of lava, a relatively thin covering, does nothing to reinforce the strength of those shattered areas. Accordingly the surfaces of the maria whilst plastic are thrown into the innumerable anticlinal folds which they exhibit, as the more rigid areas press against them. A particularly fine example of this folding is visible in the Mare Serenitatis, where a meridional anticlinal chain with syntaxis and linking of arcs stretches from border to border. A meridional line of five small vulcanoids on the face of the same mare points to a line of fracture in the crust beneath the lava, which latter, subsequent to its extrusion, was pierced by minor eruptions along the line of fracture.

The existence of mountain ranges in close association with the maria, points to the fact that these too were caused by pressure in the crust striving to accommodate itself to a contracting interior. Where the rigid crust thrust itself most intensely upon the less rigid maria, the edges of the latter were crumpled and thrown up into the ranges which in many places border the maria. That the mountain ranges were elevated after the craters is shown by the fact that the latter are occasionally seen to be distorted or deformed by the former features.

An apparent anomaly exists in the fact that whereas the lavas which rose in the earlier rifts were chilled by radiation, so that they did not issue upon the crust, the later lava-extrusions which form the maria were evidently able to flow. This can be attributed, however, to the fact that the vulcanism must inevitably have been accompanied by the discharge of gases, forming a temporary envelope which would for a while check excessive radiation of heat into space. Whereas the lava in the earlier rifts would not receive the protection against loss of heat afforded by this atmosphere, the accumulation of gases as vulcanism advanced would provide a cover under which the later phenomena, e.g. the maria, would be free to develop. This atmosphere would not long remain, but would be dispersed into space, due to the moon's inability, owing to its small mass, to retain gases for long against their diffusive tendency.

The fissures on the high ground are those formed at the inception of vulcanism. A different explanation must be offered for those fissures seen upon the maria, especially as Shaler [1] states that these

[1] Op. cit.

phenomena were amongst the last of the moon's features to be formed. These fissures appear to be rift-valleys, and their occurrence on the maria where obvious signs of compression are visible, is at first hard to explain. However, it is to be noted that the course of the fissures is at high angles to the prevailing direction of the ridges on the maria. In other words, the forces which raised the ridges would not tend to prevent the formation of the fissures, or to close them up if these latter were of earlier date than the ridges. The rift-valleys on the maria can be ascribed to faulting above fissures in the surface upon which the maria were extruded. These fissures ran parallel to the line of the compressive forces which raised the ridges. In these deep-seated fissures the molten magma was sinking with the contracting substratum, and the surface of the maria becoming relieved of support in these linear areas, sank, forming the fault-troughs now visible.

An alternative suggestion to that made previously regarding the origin of the ridges is that they were also formed above fissures in the surface upon which the maria were extruded; but these fissures were at right-angles to the compressive forces. These forces caused the magma in the deeply covered fissures to be squeezed upwards, ridging the surface of the maria. This will explain the absence of accompanying synclines, which one would expect to find if the ridges had been formed by a simple wrinkling of the crust due to lateral pressure.

It is possible that in the traces visible in places of ruined craters, we have evidences of an earlier revolution which the forces of denudation and the recent vulcanism have failed to obliterate entirely. Mountain-summits projecting above the maria, by which they are surrounded, may also be relics of an earlier period of orogenesis.

The freshness of feature on the lunar surface, and the persistence of colour gradations, induces the conclusion that a revolution has occurred recently, geologically speaking. The moon is now in a quiescent condition accumulating heat in the substratum, and therefore does not radiate any perceptible heat. As time advances, the lunar features will inevitably lose their sharpness of detail and gradation of colour, until a further period of vulcanism restores the surface to the condition which it now exhibits.

Frank Bursley Taylor's suggestion [1] that the moon was acquired by capture during the early stages of the Tertiary offers another explanation of the moon's freshness of feature. Then this can be explained by supposing that the moon has but recently arrived from a part of space where meteors do not exist. Again, if the moon were in a part of space far removed from any star, its surface temperature would be in the region of the absolute zero; nor would any

[1] *Theory of Continental Drift*, a Symposium on Wegener's Hypothesis. Tulsa, Oklahoma, 1928.

temperature-changes due to an external source be experienced to degrade its features. Even these suggestions, however, do not obviate the difficulty that the moon does not show signs of violent contractive forces, as previously set out in this article. Besides, there are so many insuperable objections to the acceptance of Taylor's theory that one hesitates to apply it to solve problems which are adequately explained, it is hoped, by the means outlined above.

Dendroseris n.g. and other Corals from Trinidad.

By Professor J. W. Gregory, D.Sc., LL.D., F.R.S.

(PLATE VIII.)

MR. J. V. HARRISON has entrusted me with the description of some fossil corals which he has recently collected in Trinidad. They include one remarkable coral which at first sight appeared to be Paleozoic, as its branches had a laminar structure resembling specimens of the Devonian *Pachypora cervicornis* in which the section has cut bands of corallites at different angles. Examination with a lens at once showed that the coral was septate, and that the resemblance to *Pachypora* was delusive.

The specimens were collected at three localities. From Tamana on the Morne River comes *Orbicella cylindrica* (Dunc.)[1] first known from the Miocene of San Domingo ; the species has been ranked as *O. cavernosa* var. *cylindrica*, by Professor T. W. Vaughan,[2] who regards it as perhaps a growth form of *O. endothecata* (Dunc.).[3]

Another Miocene species from the Central Range, from the Gravels of Brasso, on the Venado River, is *Orbicella altissima* (Dunc.).[4] This species I included in *Orbicella acropora* (L.),[5] but T. W. Vaughan [6] retains it as a distinct species. Both these Miocene localities are on the northern slopes of the Central Range of Trinidad.

The third coral from the Middle Cretaceous of Bousignac, on the Cush River, is of more novelty and interest. Its simple septation, styliform columella, paucity of endotheca, and the simple union of the corallites at first suggested affinity with *Stylina*, which,

[1] *Astraea cylindrica* Duncan, *Q.J.G.S.*, vol. xix, 1863, p. 434, pl. xv, fig. 8. *Heliastraea cylindrica* Duncan, *Q.J.G.S.*, vol. xxiv, 1868, p. 24.

[2] T. W. Vaughan, *Contrib. Geol. and Pal. Canal Zone, Panama*, p. 385, pl. lxxxix, fig. 2. The same view is repeated by Vaughan and Hofmeister, who have recorded this species from the Miocene of Gasparillo, Trinidad, Carnegie Inst. Publ. 344, 1926, p. 123.

[3] *Astrea endothecata* Duncan, *Q.J.G.S.*, 1863, vol. xix, p. 434, pl. xv, fig. 7.

[4] *Heliastraea altissima* Duncan, *Q.J.G.S.*, vol. xxiv, pp. 12, 24, pl. ii, fig. 3, from St. Croix, Trinidad.

[5] "Contrib. Pal. Geol. W. Ind.," *Q.J.G.S.*, vol. li, 1895, p. 272.

[6] T. W. Vaughan, "Contrib. Geol. and Pal. Canal Zone, Panama," *U.S. Nat. Mus. Bull.* 103, 1919, p. 379.

though usually massive, has some dendroid species, e.g. *S. carrapateirensis* Koby [1] and *S. arborea* Ach.[2]

The septa are not well preserved in thin sections, for in most cases the matrix has merged with the septa and obscured its structure. In the search for dissepiments further sections were cut and in some parts the original structure is recognizable and some fragments of septa in the matrix are well preserved. They show that the septa are those of a simple form of Fungid, and the affinities of the coral appear to me those of a primitive Lophoserid.

Dendroseris n.gen.

Diagnosis.—Lophoseridae with a branched, dendroid corallum of a lamellar structure. The branches consist of superposed segments.

Corallites with a well-defined tubular wall. They are usually united by the costæ, but occasionally by the wall.

Septa few, simple. Columella styliform; well developed. Pali none; endotheca scarce.

Type Species.—D. harrisoni, Mid-Cretaceous, Trinidad.

Dendroseris harrisoni n.sp.

Corallum of stout, more of less cylindrical branches, from 8–20 mm. in diameter. The branches are free, straight, fairly near one another, and approximately vertical, and parallel; they subdivide rarely. Each branch consists of vertical series of discoid segments, most of which are composed of two-three layers of corallites.

Mature corallites from 1 to 1·25 mm. in diameter. Septa hexameral, with usually two cycles present. The six short primary septa in the upper part extend about half-way inward from the wall, but in the lower part of a corallite the septa are longer and may unite with the columella. The secondary septa are very short and may be represented only by a thickening of the wall.

Columella elliptical or subcircular in section, solid; it is not seen in some young corallites. It may be free or joined by the six primary septa.

Endotheca sparse. No dissepiments.

Costae usually free externally, but some of them unite with those of adjacent corallites.

Dimensions.

Corallum largest block is about 225 by 225 mm.

Branches, diameter 10–20 mm. A vertical stem, 75 mm. long, has one bifurcation, above which the diameter is 10 mm.; below the bifurcation the diameter is usually 15 mm. in diameter and with the maximum of 20 mm.

[1] F. Koby, *Polyp. jur. sup. Portugal*, 1905, p. 28, pl. vi, fig. 1–4.

[2] d'Achiardi, "Cor. Giur. Ital. settentrionale," *Atti Soc. tosc. Sci. nat.*, iv, 1880, p. 58, pl. xix, fig. 8; and Ogilvie, "Kor. Stramberg Sch.," *Pal. Stud. Grenzsch. Jura and Kreide*, vii, p. 169.

Laminae from 3 to 6 mm. thick.

Corallites, diameter up to 1·25 mm.

Distribution.—Mid-Cretaceous. Bousignac, Cush River. Central Range, Trinidad.

Affinities of the Genus.

The coral by its synapticular structure, simple tubular corallites, scanty endotheca, and simple solid septa is clearly a member of the compound Lophoseridæ. Many of the genera in this family have a laminar foliated growth, and *Dendroseris* is therefore a form in which the folia grow superposed into thick, more or less cylindrical, branches.

The nearest known ally is *Phylloseris* Tomes,[1] from the Lower Oolite of Gloucestershire. *Dendroseris* differs from that genus by having a styliform columella, whereas Tomes in his diagnosis of the genus says it has no columella, but in his description of the type species says there is a small columella seen in worn corallites. A parietal columella is also present in *Phylloseris heteromorpha* (Tomes),[2] The corallum of *Phylloseris* moreover is flat-topped and massive instead of in free branches.

Protoseris Edwards and Haime is also a near ally, but has a papillary columella and the folia of which the corallum consists are funnel-shaped.

Dendroseris has some resemblance to *Thamnoseris*[3] owing to its small corallites and styliform columella; but in *Thamnoseris*, as in the other Thamnastream corals, though in some species the corallum grows in thick overlapping layers, there is no such foliar structure as in many Lophoserids and in this genus.

Mr. Harrison has referred me to G. A. Waring, "The Geology of the Island of Trinidad, B.W.I., with Notes on the Palaeontology by G. D. Harris," *John Hopkins University Studies in Geology*, No. 7, Baltimore, 1926, for a recent general account of the geology and palaeontology, but there is no reference in it to any similar coral.

Dendroseris, being a new genus, gives no definite independent evidence of age. The Lophoserids are mainly Kainozoic; but are represented in the Jurassic by some primitive genera such as *Protoseris* and *Phylloseris*. This genus being a simple form of *Lophoserid* is probably pre-Kainozoic and doubtless post-Jurassic. Its characters suggest that its age is Cretaceous, and Mr. Harrison considers its horizon as Middle Cretaceous. The characteristics of the coral are consistent with that date.

The Pointe à Pierre shales are usually assigned to the Lower Cretaceous, but according to Professor Illing they are possibly Cenomanian; and he refers to the presence of large masses of lime-

[1] *P. rugosa*, R. F. Tomes, "Madr. Inf. Ool.," *Q.J.G.S.*, vol. xxxviii, 1882, pp. 446-7, pl. xviii, fig. 8–10.

[2] Tomes, "Inf. Ool. Madr.," Geol. Mag., 1886, p. 450.

[3] de Fromentel, *Introd. Et. Polyp.*, 1858, p. 241.

stone in the shales of the Central Range. Professor Illing's conclusions[1] are therefore consistent with the Middle Cretaceous age of the Bousignac limestone, though nothing like this coral has apparently been previously found in Trinidad.

EXPLANATION OF PLATE VIII.

FIG. 1.—Part of a vertical section, natural size, showing the laminar structure of the branches.

FIG. 2.—A cross section, × 4 dia.

FIG. 3.—The section in the central part of the figure is nearly vertical but oblique; the branches on the top and bottom of the figure show cross sections; where the section in the middle branch passes vertically along a corallite the septa show the synapticular structure. × 4 dia.

FIGS. 4*a* and 4*b*.—Parts of a section through another specimen, × 7 dia. It shows some corallites in cross-sections; and others in vertical section, with the synapticular structure, which is also shown in the fragments of septa in the matrix above the letter S in Fig. 4*a*.

The Quartz-basalt of Taradake, Japan.

By T. OGURA.

(PLATE IX.)

AT several localities in Japan quartz-basalts are known. Professor S. Kodzu mentioned the mode of occurrence and chemical properties of the quartz-basalt of Kasayama, Province Nagato (1).[2]

In the neighbourhood of the Taradake volcano in south-western Kyūshū, the dacite and basalt intrude into or flow over the Tertiary sediments and are covered by agglomerate and by pyroxene- and hornblende-andesites. The order of eruption of dacite and basalt is obscure in this district, owing to the scanty exposures of dacite, but it is stated that in the northern part of Takeo (20 km. north of the Taradake district) the dacite overlies basalt (2). In the writer's previous report (3), he pointed out the earlier eruption of dacite in the Taradake district. Recently he had an opportunity to visit the district, and fortunately found a quartz-basalt which seems to him to throw light on the relations between the dacite and basalt.

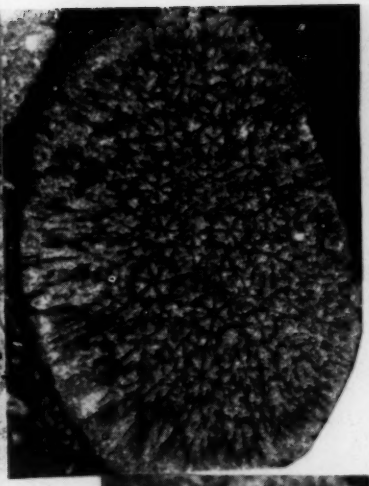
The quartz-basalt now under consideration crops out at Yosaki, to the south-east of Ōmura, which is situated at the western foot of the Taradake volcano. The country round Yosaki consists of Tertiary sandstone, dacite, olivine-basalt, quartz-basalt, agglomerate, and alluvial deposits as shown in the accompanying map (Fig. 1).

The dacite crops out on both sides of the alluvial plain of Suzutagawa, and good exposures are observed in the railway cuttings.

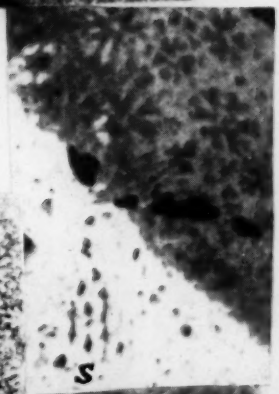
[1] V. C. Illing, "Naparina Region of Trinidad," *Q.J.G.S.*, vol. lxxxiv, 1928, p. 11.

[2] Figures in parentheses refer to References at end of article.

1 Nat. Size

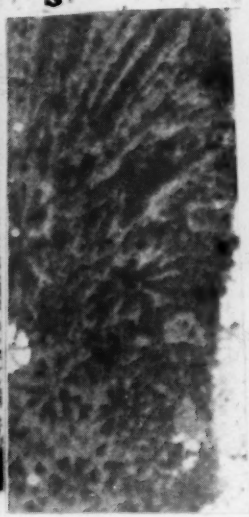


2
×4



4ª
×7

3×4



4ᵇ
×7

The rock is white, with phenocrysts of quartz and oligoclase, as well as a little hornblende. The oligoclase is in prismatic or tabular crystals 1 mm. long, and is characterized by Karlsbad and pericline twinning and zonary banding. The quartz occurs in corroded bipyramidal crystals. The hornblende is changed to opacitic substance and apatite is present in well-shaped prismatic crystals up to 0.5 mm. in length showing pleochroism. The groundmass is felsitic.

The olivine-basalt crops out at the point of Kushimasaki and on the summit of Hidake. The rock is composed of felspar, augite, olivine, and magnetite, with holocrystalline intersertal groundmass. The little felspar phenocrysts are of prismatic habit, about 1 mm.

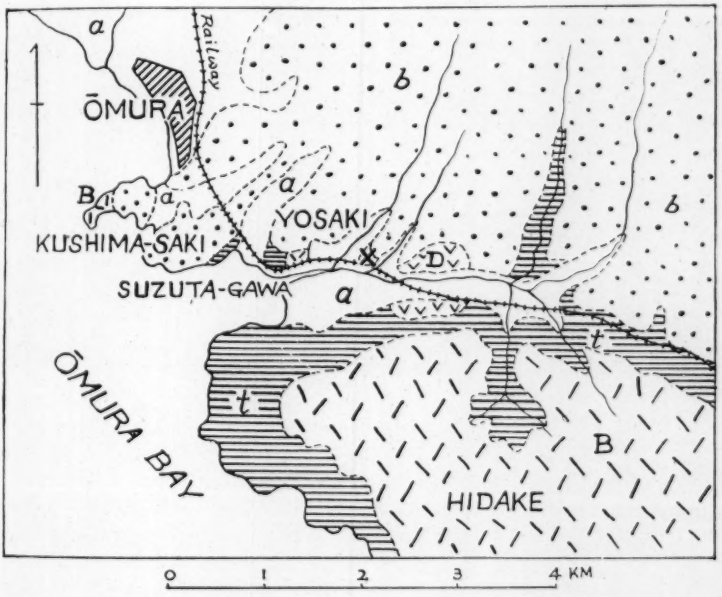


FIG. 1.—Geological Map of the environs of Yosaki. *a*, Alluvium; *t*, Tertiary; *b*, Agglomerate; *B*, basalt; *D*, dacite; *X*, Quartz-basalt.

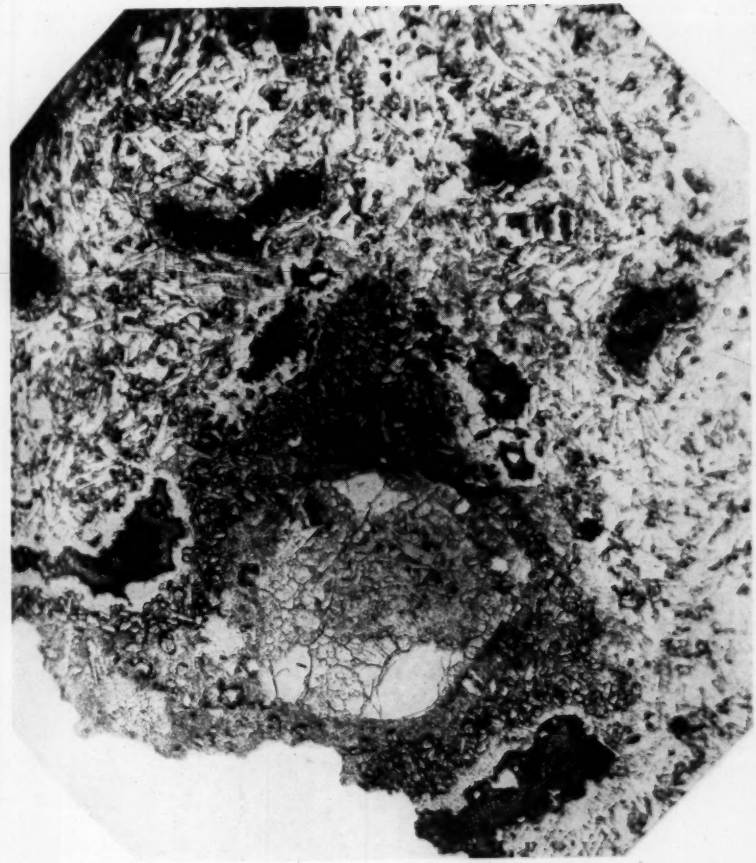
in length, and show simple albite twinning. The felspar of the groundmass is in small lath-shaped crystals, the augite in short prisms, and the olivine in well-shaped or rounded crystals, showing a dark brown colour, due to decomposition, along cracks or on the margin.

The quartz-basalt invades the Tertiary sandstone which crops out at the foot of the hill. The rock is of dark colour with distinct phenocrysts of quartz and felspar. The felspars are 2 mm. in length, rather rounded and corroded. The zonal arrangement of inclusions

and zonary structure is very remarkable and the polysynthetic twinning is invisible. This felspar is oligoclase of similar composition to that of the dacite. The writer considers the felspar in both cases as having the same origin. The olivine is in irregular shaped crystals about 0.5 mm. in dimensions and mostly changed to calcite or a light-brownish grey substance, but with residual cores. The augite forms short colourless prismatic crystals. The quartz occurs as rounded and corroded crystals, 0.5 mm.–1.0 mm. in size. The alteration of the quartz is very remarkable (Plate IX).

In one section the quartz is traversed by numerous cracks filled with an amorphous yellowish-brown substance. In another section the quartz is divisible into three different parts as a result of alteration; one part of the original quartz is an aggregate of prismatic crystals embedded in the carbonate and glassy substance, the other part cracked and dull, while there is an unaltered residue. These three parts show transitions. The prismatic crystals in the altered part of the quartz are 0.1 mm. long, without distinct terminal faces, colourless, transparent, and often transversely cracked. They show faint birefringence, the extinction being parallel to the elongation. The index of refraction is far less than that of quartz. These crystals are identified as tridymite. The cracked part of the quartz shows simultaneous extinction with the unaltered residue of quartz and it may be in the transition state from quartz to tridymite. The unaltered part is colourless, transparent, and fresh. The quartz is coated by thin layers of a glassy substance, augite, and carbonate matter arranged from within outwards. The glassy substance is very similar to that in which the tridymite crystals are imbedded. The augite is represented by an aggregate of small colourless prismatic crystals scattered in the glassy substance. The carbonate matter constituting the outermost layer is of a yellowish brown colour and shows fibrous structure. This alteration-phenomenon of the quartz and the surrounding layers may be especially mentioned. The quartz is a single crystal showing simultaneous extinction. The groundmass is intersertal, consisting of lath-shaped felspar, microlithic augite, and magnetite grains, with much colourless devitrified glass and chalcedony. These felspars and augites are arranged tangentially around the phenocrysts.

The inversion temperature under atmospheric pressure between quartz and tridymite is 870 ± 10 degrees C. In his careful experiments on silica, Dr. C. N. Fenner obtained tridymite crystals by the inversion of quartz in a tungstate melt (4). The tridymite obtained at the temperature of 1300 degrees C. after 23 hours heating formed tabular crystals and at a temperature of 900 to 1200 degrees C. after 140 hours, elongated or lath-shaped crystals were obtained, the extinction of which is parallel to the elongation. In the quartz basalt, the tridymite forms elongated and lath-shaped crystals, so that it resembles that of the forms obtained at the temperatures of 900 to 1200 degrees C. in Dr. Fenner's experiments: that is to say,



Quartz-basalt of Yosaki, showing the Quartz changed to Tridymite with Surrounding Layers. × 50.

[To face p. 70.

the quartz grains first formed in the dacite were partly converted to tridymite at 900 to 1200 degrees C. in the basalt magma.[1]

The porphyritic quartz grains of basic rocks are, on the one hand, referred to as primary by Dr. Harker (5); on the other, Dr. Daly maintains their secondary character (6).

The formation of the quartz-basalt of the Taradake district may be explained by magmatic differentiation. Phenocrysts of quartz and oligoclase occur in both dacite and quartz-basalt. The phenocrysts of quartz and oligoclase in the upper acid magma (dacite) partly sank down into the lower basic zone of the magma, and became ingredients of the basic rock (basalt). After the acid intrusion came the basic extrusion which contains phenocrysts similar to those in the acid rock.

The sequence of dacite and quartz-basalt therefore seems to be very clear, viz. first dacite, followed by quartz-basalt and olivine-basalt.

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[The problem of porphyritic quartz-grains in basic rocks has also been discussed by J. W. Judd, J. P. Iddings, J. S. Diller, G. W. Tyrrell, Thomson, Larcombe, and C. N. Fenner.]

In Defence of *Bothriocidaris.*

By Herbert L. Hawkins, D.Sc., F.G.S., Professor of Geology in the University of Reading.

TWO rival hypotheses as to the origin of the Echinoidea are prevalent to-day. One of them postulates as the primitive form an organism built of a few large plates arranged in vertical series; the other demands that the earliest types should have been "scaly", with many small plates which were regular only along the radii. Those who hold the former hypothesis see in the Ordovician *Bothriocidaris* a close approximation to their ideal; supporters of the latter claim that the Silurian genera *Echinocystis* and *Palaeo-*

[1] In the metamorphosed Torridon sandstone of the Isle of Rum, originally composed of grains of quartz and felspar, the tridymite occurs in slender rods, tending to a radial disposition, but it is now converted to quartz.

discus represent fairly well the ancestral qualities of the class. So long as *Bothriocidaris* is regarded as a true Echinoid, the Silurian forms lose much of their claim to be considered truly primitive; the chronological sequence is against them.

There can be no two opinions as to the truly Echinoidean nature of the Silurian types; but there is room for some uncertainty as to the taxonomic position of *Bothriocidaris*. For this reason any additional information about this remarkable form is welcome. Such information is the more acceptable when obtained by such an experienced and careful observer as Dr. Th. Mortensen of Copenhagen. It is all to the good that neontologists should occasionally turn their attention to fossils—good for them and for palaeontologists. It is also good for discussion, for the two kinds of biologists have very different outlooks.

Dr. Mortensen's recent memoir on "*Bothriocidaris* and the origin of the Echinoids" (*Vid. Medd. Dansk. nat. Foren.*, 1928, Bd. lxxxvi, pp. 93–122) adds very materially to our knowledge of the genus, and includes decided views on the problem. Before proceeding to a critical review of parts of the memoir, I wish to make two points clear. In the first place, I have every confidence in the accuracy of the observations made and recorded by Dr. Mortensen; my criticisms are directed against his interpretations of the facts. Secondly, Dr. Mortensen, having satisfied himself that *Bothriocidaris* is not an echinoid, joins the ranks of the supporters of the "scaly" hypothesis. In my opinion, the problem of the nature of the primitive echinoid remains unaffected, even if Dr. Mortensen's interpretation of *Bothriocidaris* is right. If *Bothriocidaris* is a peculiarly specialized type of diploporitan cystid showing many Echinoid features (as Dr. Mortensen thinks), it might still be claimed as a form ancestral to the Echinoidea. Whether it is called an "Echinoid-like Cystid" or a "Cystid-like Echinoid" is largely a matter of arbitrary choice. Dr. Mortensen selects the Edrioasteroidean Cystid *Stromatocystis* as showing an approach to the Echinoid original, and so gives a precedent for anyone who chooses to regard the "Diploporitan Cystid" *Bothriocidaris* in that light. The sole gain to the "scaly" hypothesis achieved by ousting *Bothriocidaris* from the class Echinoidea seems to lie in opening up a *possibility* that the earliest sea-urchins may have been "scaly"—a possibility that is improbable if the oldest known form had the opposite qualities.

We can now turn to an analysis of Dr. Mortensen's description and interpretation of the structure of *Bothriocidaris*.

(*a*) The *ambulacra* (pp. 94–6). Very little addition is made to our knowledge of these areas. Although he does not specifically mention the point in this section, Dr. Mortensen admits (pp. 105–6) that the radial water-vessel was beneath (i.e. inside) the ambulacral plates. He finds that the pore-pairs are not quite vertically superposed as was believed—such obliquity as he indicates shows them

to be inclined in the directions normal in Echinoids, though at a rather steep angle. He re-figures the traces of tube-feet (which show indications of the presence of spicules in their walls). The preservation of even a trace of these perishable structures is a miracle for which we should be thankful; it seems a little ungracious to complain that the distal sucking-discs cannot be detected (if they ever existed). On the supposition that these discs were really absent, no deduction of importance can be based. Plenty of Echinoid podia are without them—their presence merely indicates that the tube-feet were employed for the secondary function of adhesion.

Dr. Mortensen dallies with the suggestion of Schmidt that the sunken peripodia of *Bothriocidaris* resemble articular facets for the support of brachioles; but he is forced to admit that there is no evidence whatsoever that they were of this nature. By inference he seems to consider that the "pore-pair" is to be regarded as a "diplopore". But he still calls the traces of the "soft" projection from it a "tube-foot"; so that the matter is left far from clear. If the "peripodium" were a brachiole-facet, it could hardly have given issue to a tube-foot; if the tube-foot is rightly so named (or if it be a *papula* from a diplopore as tentatively suggested by Dr. Bather, p. 106, note) it could not also be a brachiole. There is, in short, nothing *definitely* Cystidean about the ambulacra, while there is much that is emphatically Echinoidean. In my opinion, there is no complication in interpreting them as normal Echinoid ambulacra; difficulties arise only when an attempt is made to explain them as something else.

(*b*) The *interambulacra* (pp. 96–7). Dr. Mortensen confirms and lays emphasis upon the discovery by Yakolew of the existence of some irregularity in the approximately uniserial disposition of the interambulacral plates. Some of these plates seem to be somewhat cuneiform (occasionally to such a degree that one may fail to extend right across the area); and in one case a plate is seen to be divided into two plates which lie on the same horizon. These irregularities are exceedingly interesting, and the former type certainly cannot be dismissed as merely accidental. Dr. Mortensen naturally compares the interambulacrals of *Bothriocidaris* with the similar, though more complex, interlocking plates in the interradius of *Proteroblastus*, and with the even simpler plates of the same region in *Estonocystis*. The legitimacy of this comparison is undoubted, so long as the outlines and distribution of the plates are alone considered. But what of the tubercles with their moveable radioles that are scattered over the interambulacrals of *Bothriocidaris*? And why should the comparison not include the plastronal region of such a Spatangid as *Sternotaxis*? There the resemblance is complete in ornament as well as in plating. In any interpretation of the interambulacral structure of so isolated a type as *Bothriocidaris*, there would seem to be quite as much reason for regarding

faint tendencies to alternation and biseriality in the plates as an incipient stage in the production of two columns as in supposing it to be a relic of past " scaliness ". Where the disposition of the plates gives equivocal evidence, the deciding voice must come from the ornament. This is emphatically of an Echinoid type, and unlike anything known in Cystids or even in Pelmatozoa.

(*c*) The *apical system* (pp. 97–101). There are three serious problems connected with the apical system. The first concerns the madreporite, the second the identification of genital plates, and the third the presence of ocular and genital pores. The first problem is extraordinarily interesting, but it bears no relation whatever to the taxonomy of *Bothriocidaris*. Three observers (Jaekel, Yakolew, and Mortensen) are agreed on the identification of certain markings on one of the " ocular " plates as a madreporite ; one (Jackson) reserves judgment. Certainly a radially placed madreporite is an unique anomaly ; but it would be no more appropriate in a Cystid than in an Echinoid. Supporters of the " Cystid-hypothesis " can get no help from the feature ; while champions of the " Echinoid-hypothesis " can gather no greater comfort from it than the knowledge that the madreporite was at least in one of the plates of the apical system.

Dr. Mortensen has failed to identify with certainty any of the apical plates as genitals. His figures (6, No. 1, p. 99, and 8, No. 1, p. 100) show five fairly large interradially placed plates alternating more or less regularly with the oculars ; but there seems to be nothing except their position to mark these plates as genitals. Miss Hampton and I (*Q.J.G.S.*, 1927) failed even more completely to find any traces of genital plates in *Echinocystis* (although we detected the oculars). If Dr. Mortensen insists on invoking the feebleness or absence of genital plates as indication of the non-Echinoid nature of *Bothriocidaris*, he will have to eject *Echinocystis* from the class on the same count.

On pages 119–20 Dr. Mortensen expresses his agreement with most modern Echinologists that the apical plates of Echinoids are in no way homologues of the calycal plates of Crinoids. On page 101 he seems convinced that the apical plates of *Bothriocidaris* are homologous with the " calycal " plates of Cystids. He gives a figure of a *Protocrinites* (Fig. 9. p. 101) which he designates the " apex " ; is this a misprint or an expression of his convictions ? In any case, the comparison seems to me rather far-fetched, for *Protocrinites* shows no signs of pentamerous symmetry in its " calycal " plates, whereas *Bothriocidaris* is perfectly five-rayed. The chief reason for the suggestion that the " apical " plates of *Bothriocidaris* are not an apical system seems to be the failure to detect any pores in them. Dr. Mortensen shows here, as elsewhere, his neontological training ; for he is convinced that features he cannot see in a few specimens were really non-existent. Greater familiarity with fossil material and with the nature of fossilization

would have lessened his confidence. But if we grant him all his points with respect to the " apical system ", we are entitled to ask him to explain the presence of the periproct in the centre of a Cystidean " calyx ", and to produce evidence that the madreporite is ever placed on a calycal plate in any Pelmatozoan. Here, as in the case of the ambulacra, the structures are easily interpreted as an inadequately preserved (or incompletely developed) Echinoid feature ; while an attempt to explain them as anything else leads to confusion.

(*d*) The *peristome* (pp. 101–3). If there was one feature in *Bothriocidaris* that weakened our faith in its Echinoid affinities it was to be found in the radial position of the structures identified as teeth. Dr. Mortensen seems to have removed this embarrassing problem altogether ; for if his observations are correct (as I am convinced they are), the so-called teeth of *Bothriocidaris* are not teeth at all, but merely plates. The previous accounts and figures of these structures seem to have included so much reconstruction that they have been misleading. Dr. Mortensen has found " indications " of tubercles on the " teeth " of a specimen of *B. pahleni* ; and in the appendix to his memoir (p. 121) he confirms this observation in another beautifully preserved example, where the disposition of the critical ossicles conclusively shows them to be plates. It is not quite clear why they should be claimed as " coronal " plates—they might be peristomial ; but the point is a small one. I am fully prepared to accept, with a feeling of relief, Dr. Mortensen's conclusion that " these plates do not correspond with the teeth of Echinoids."

Having demonstrated that the teeth of *Bothriocidaris* have not been seen, the neontologist in Dr. Mortensen takes it for granted that they never existed. If arguments of this kind were admitted, there would be a remarkable irregularity in the distribution of jaws among fossil Echinoids. Quite a small proportion of the Perischoechinoida, by no means all of the Cidaroida, and not more than half of the " Diademoida " (Centrechinoida) can have possessed teeth on such an assumption. Until 1892 almost all workers were agreed that the common Cenomanian Holectypoid *Discoidea cylindrica* (Lam.) was edentulous—its lantern and teeth are now known in full detail and in dozens of specimens. But we do not yet know whether the even commoner Senonian *Conulus albogalerus* Leske had a lantern or not. It possesses a perignathic girdle which gives presumptive evidence of the presence of jaws, but all attempts to find them have had negative results. It would be indeed remarkable if the lantern were known in a rare type like *Bothriocidaris*, especially since no specimen (so far as I am aware) has been seen from within. Even on the assumption that Dr. Mortensen's guess is correct, and that *Bothriocidaris* had no jaws, there would be no reason to deny its Echinoid position therefore, for possession of jaws is not a diagnostic essential for the class. All that we can say with

confidence on the subject is that if jaws *were* present in *Bothriocidaris* there is now no reason to suspect that there was anything peculiar in their orientation.

Strangely enough, Dr. Mortensen seems scarcely to realize the paramount importance of his discovery. On page 104, for instance, he uses the assumed radial position of the teeth as an extra prong on which to impale the unfortunate corpse of Thiéry's speculation that *Bothriocidaris* might be an immature stage of *Palaeechinus*. And yet, on page 109, Dr. Mortensen tells us that " we must regard it as an established fact that *Bothriocidaris* had not a true Echinoid dental apparatus ". A few lines above this confident assumption of a negative " fact ", we find the statement that " the radial position of the ' teeth ' is . . . entirely irreconcilable with Echinoid morphology ". And a few lines below it, a combination of these two irreconcilable statements with a few possibilities and assumptions leads to the peroration " *Bothriocidaris . . . in fact . . .* cannot be considered as an Echinoid at all " ! Dr. Mortensen must forgive a sceptic for failing to be carried away by the fervour of his rhetoric when it appears in cold print.

If we summarize the evidence brought forward in part I (on which hangs all of part II and much of part III), we get some such view of *Bothriocidaris* as follows. The ambulacra are typically Echinoid, except that the peripodia are of an unusual pattern. The interambulacra are plated in a manner that can be matched in a few specialized Cystids ; but they support tubercles and radioles that are perfectly Echinoid in character. The apical system is incompletely known ; no pores have been detected in its plates, but there are five radially placed plates in the position of oculars, and five alternating ones that are in the position of genitals ; a madreporite is believed to occur on one of the " oculars " ; a state of things unknown elsewhere in Echinoderms of any class. The dental apparatus, if present, is quite unknown.

It is a testimony to the accuracy and honesty of Dr. Mortensen's work that his record of the facts is so lucid and unbiassed in spite of his decided convictions. But the facts that he has brought forward scarcely seem to justify eight pages of dogmatic assertion that *Bothriocidaris* cannot possibly be regarded as an Echinoid.

Although in my view the last two sections of the memoir are premature, there are some aspects of them that cannot be allowed to pass without comment. On page 107 Dr. Mortensen admits that the conformity with Lovén's law shown by the ambulacral plates on the peristomial border of *Bothriocidaris* is a " weighty argument " in favour of the Echinoid-hypothesis. He suggests that *if* the same condition occurred in Protocrinite Cystids (where it has never been seen, nor could it be expected in the absence of pentamerous symmetry) the argument would lose weight. Alternatively he says that such an arrangement of the plates might be due to unexplained mechanical reasons, in which case " it might have arisen inde-

pendently in *Bothriocidaris* ". Smothering it with two speculations based on possibilities for which there is not a shred of evidence, Dr. Mortensen passes on from this one damaging, but established, fact, to proceed to fresh conquests. On the same page (p. 107) he claims that the trifling irregularities he has detected in the uniserial sequence of the interambulacral plates *prove* " that the monoserial condition . . . is in itself by no means a primitive, but, on the contrary, a very specialized condition ". I must confess that I fail to see how it can prove anything of the sort, one way or the other.

The paragraph (p. 108) in which Dr. Mortensen attacks the value attached (chiefly by Jackson) to the persistent primordial interambulacral plates of later Echinoids is to me much more intelligible ; and his suggestion that the narrowness of the area in that region leaves room only for one member of the alternating series is not only reasonable but illuminating. A tall, narrow test like that of *Bothriocidaris* would need only one interambulacral column in each area ; the introduction of two or more columns in later forms may well have been a device for increasing the girth, and so the capacity, of the test. When, however, Dr. Mortensen states that the persistence of the primordial interambulacrals is the " main argument " for considering *Bothriocidaris* as a primitive Echinoid he rather overstates the case.

The indictment of *Bothriocidaris* continues with the ominous declaration that " the characters of the apical system and the peristome very decidedly speak against regarding it as an Echinoid." In respect of the peristome, one feels inclined to wonder if that sentence was written before its author discovered that the so-called teeth were nothing of the sort ! As for the apical system, there are two points only that are claimed to speak thus " decidedly ". First comes the radial position of the madreporite. If the interpretation of that structure is correct, and if its taxonomic importance is pressed, *Bothriocidaris* may have to be excluded from the Echinoidea, but it cannot find a resting-place in any other class of the phylum. Dr. Mortensen has not yet suggested that *Bothriocidaris* is not an Echinoderm. As to the second point that so " decidedly " disproves the Echinoid affinities of the form, we are told that " the *probable* absence of true genital plates *is* a fundamental difference from the Echinoids " (the italics are mine).

After such a paragraph it is without surprise that we read (p. 109) that the interambulacral structure of *Bothriocidaris* " must be said to be perfectly identical " with that of such forms as *Proteroblastus*. Are not radioles and tubercles parts of the interambulacral structure ? If so (and even if they are dismissed as independent developments, p. 111), the " identity " is scarcely " perfect ".

The internal radial canal of *Bothriocidaris* (which was a typically Echinoid feature on p. 105) loses all its terrors on page 111. With a stroke of the pen Dr. Mortensen proves that adoption of a free mode of life induced this descendant of *Proteroblastus* to lose its

ambulacral furrows and to transfer its radial canal to the interior. In spite of this change (the mechanics of which are unexplained), *Bothriocidaris* still remained a Cystid. If such an argument is to stand, future diagnoses of the Cystidea will need to be rewritten and reversed in one of their essential factors so that one member may possess most of the diagnostic features of the Echinoidea!

Having conclusively proved (to his own satisfaction) that *Bothriocidaris* is an unique kind of Cystid, not far remote from the Diploporita (displaying curious, but quite negligible, tendencies towards Echinoid structure), Dr. Mortensen expounds in part III his views on the origin of the Echinoidea. On page 113, on his way to the statement that "there can be no doubt that the many interambulacral plates represent the more primitive condition", he refers to the numerous interambulacrals in the Silurian forms *Echinocystis* and *Palaeodiscus*. He finds in this early appearance of multiple plating evidence (indeed, proof) that it is a primitive feature. But surely Dr. Mortensen is aware that one of the periods of maximum and rapid specialization occurs shortly after the inception of a group of organisms. Are we to assume that the weird characters of a Permian *Naosaurus* represent at all closely the features of the primitive Reptile? Was *Pterichthys* a living image of the original fish? As for the Perischoechinoids, they show (in some lineages) a steady progress in "primitiveness" of this sort in their interambulacra, that culminates in the Carboniferous period!

Having admitted that the primitive ambulacrum consisted of two columns only, and that any increase on this number indicates specialization, Dr. Mortensen finds it hard to understand how the interambulacra could be modified in a corresponding way. His introduction of *Aristocystis* into the argument seems to me quite beside the point. *Aristocystis* surely represents a far more primitive kind of Echinoderm than *Bothriocidaris*—it is, as it were, on the threshold of the radial symmetry into which *Bothriocidaris* has entered so fully. There seems no logical reason why interambulacra should not become multicolumnar, since we are agreed that ambulacra can do so.

In his effort to demonstrate the primitive features of *Echinocystis* and *Palaeodiscus*, Dr. Mortensen throws caution to the winds. He adverts to the failure of Miss Hampton and myself (*Q.J.G.S.*, 1927, vol. lxxxiii) to determine the columnar arrangement of the interambulacral plates in *Echinocystis* (scarcely realizing that most of the material of that genus does not show that there were any separate plates at all), and claims that there was no columnar arrangement present. He seems to include *Palaeodiscus* in the same category; but we showed (*l.c.*, text-figs. 5 and 6) that in *Palaeodiscus* the interambulacral plates on the adoral surface are few, large, and arranged exactly in the columnar plan normal to later Perischoechinoids. The ambulacra of *Echinocystis* are complex in a manner that Dr. Mortensen allows to be highly specialized; while *Palaeo-*

discus has relatively simple and primitive ambulacral plating. The interambulacra of *Echinocystis* seem to be composed of numerous small plates; those of *Palaeodiscus* are built of a few large plates whose orderly arrangement is known. While it is doubtless true that advanced and retarded structures may occur in one and the same organism, is it not stretching the arm of coincidence to invoke this double case for forms that were living together in the same environment?

Fortified by arguments of the kind here quoted, Dr. Mortensen adopts *Stromatocystis* Pompeckj, a Cambrian Edrioasteroid, as the nearest approach to the Echinoid ancestor yet found. It may be so. But I, for one, await some evidence that *Bothriocidaris* is unworthy to be called an Echinoid, or at least a forerunner of the class. Until that evidence is forthcoming (and I cannot find it in Dr. Mortensen's memoir), *Bothriocidaris* remains for me a representative of the primitive Echinoid type, from which all of the latter forms I know could have been derived, and towards which many of them show, in the decline of their powers, a tendency to return.

The Caves of Bermuda.

By A. C. Swinnerton (Antioch College, Yellow Springs, Ohio).

Introduction.

In August, 1928, the writer made a study of the freshwater solution caverns of Bermuda, and their relation to the general geology of the islands has been productive of some observations and conclusions. Various kinds of obligations have been incurred in connection with this study; since it is intended that more complete publication will follow none of these obligations will be acknowledged here. The work was carried on by financial support extended through the Division of Geology of Harvard University.

The caves of Bermuda are caves in miniature to those who are familiar with the caverns of Kentucky and Virginia. The accessible parts are not over a few hundred yards in length, although it is undoubtedly true that a network of passages underlies much of the cave area. The presence of sea water in the caves, the variously coloured deposits stained with orange cave-earth, and fossil soils contrasted with the many brilliant white stalactites and stalagmites make the caves extremely picturesque and memorable spots for the tourist to visit and likewise for the geologist to study.

The outlines of the geology of Bermuda are well known.[1] A

[1] Of many references the following may be cited: Nelson, R. J., *Trans. Geol. Soc. London*, ser. II, v, 1840, pp. 103–23. Verrill, A. E., *Trans. Conn. Acad.*, xii, 1907, pp. 45–348. Bullen, R. Ashington, Geol. Mag., 1911, pp. 385–95, 433–42. To Nelson belongs credit for recognizing the aeolian nature of the later rocks; Verrill's paper is the most comprehensive account of the geology of Bermuda.

truncated volcanic pile is covered by a series of limestones interbedded with thin layers of soil. The oldest of the limestones is known as the Walsingham formation. It is uncertainly of early Pleistocene or late Pliocene age. It is thoroughly consolidated, and is in part of marine origin, and in part aeolian. Overlapping the Walsingham lies a thin series of marine limestones, and in turn over the whole island occur the relatively modern, porous, dune limestones. In recent years Sayles [1] has studied the included layers of soil and has interpreted them as corresponding to high sea-level stages during the interglacial periods of the Pleistocene.

Primarily the caves are the zones of solution by downward migrating rain-water along steeply dipping and intersecting joints in the compact Walsingham limestone. Crystal, Wonderland, Leamington, Admiral's, Bassett's, to mention only the largest caves, show clearly the control of jointing in the formation of large openings. Crystal, Bassett's, and Admiral's caves include tunnel-like passages also. The cave in Tucker's Town is the only large one in which the effect of joint control is not clear.

Rate of Growth of Stalactites.

Considerable attention was given to the rate of growth of stalactites, stalagmites, and other cave deposits, because of the appearance of two, perhaps three, generations of stalactites. Aside from the pending quantitative answer to be given from the analysis of drip-water specimens, it is possible to assert that very little reliance can be placed upon estimates of the time required for actual deposits to form. The question of chemical equilibrium is complicated, and at present it is quite impossible to deduce an average rate of growth.

To illustrate: Some of the Bermuda caves have been open to the public for fifty years. At first burning torches and fires were used for light, later acetylene, now electricity. In the caves formerly open to the public, like Admiral's cave, clean white stalactites, presumably new, grow from the tips of old soot-coated stalactites. It seems likely that the clean ones have grown since the time when the caves were illuminated with smoky lights—not over twenty years ago. One old stalactite may have five clean ones hanging from it. One of these new ones may be half an inch in length, another may be 6 inches; one may be of large diameter, another very small.

An excellent illustration of the rapidity of stalactitic growth was found in the presence of stalactites and stalagmites on the porches of the Shore-Hills Hotel. The seepage of the water through the Bermuda stone (the sawed dune-limestone) roofing of the veranda has resulted in the growth of string-like stalactites from the cornice

[1] Sayles, R. W., *Geol. Soc. Am., Bull.*, xxxv, 1924, pp. 68–9. Sayles, R. W., and Clark, T. H., ibid., *Bull.* xxxvi, 1925, pp. 141–2.

and of flat stalagmites on the floor beneath. The building was erected seventeen years ago, but it is unlikely that the present stalactites are more than as many months old because the deposits are granular and fragile and the strong winds frequently break them. But so rapid is the growth of these stalactites that one is at present $4\frac{1}{2}$ in. long.

Constructional and Destructional Depressions.

The absence of the normal type of stream drainage is a feature which the geologist notices at once in Bermuda. So porous are the later rocks that the rainfall sinks through the surface. Gullies and the usual surface channels are entirely lacking. The depressions resolve themselves into two classes: the constructional type which is formed between sand dunes, and the destructional type developed as the result of solution of portions of the rock. The largest visible example of the first kind is found in the Devonshire Marshes. The Walsingham cave region shows many examples of the collapse or solution depression: the "Jungle" is located in a specially well developed one.

The extent to which the collapse of the roof of caves has affected the history of Bermuda is not yet clear. The central Walsingham area borders both Castle Harbour and Harrington Sound. It is obvious that in many places along both shores such collapse has enlarged the bays. But the contention of some previous writers [3] that these large embayments in their entirety are possibly the result of cavern collapse is probably demanding too much of sub-surface erosion.

Relation of Sea-level and the Water Table to the Formation of Caves.

The great contrast between sea-level erosion within the caves and along the shore line is an observation which bears definitely on the problem of the origin of solution caves. Along the shore the progress of erosion has been marked. Both the compact and the less consolidated limestones have yielded to the play of the waters with many picturesque results on a major and minor scale, at present sea-level, and at a level between 10 and 15 feet above sea-level.

Within the caves so slight has been the influence of sea water on the submerged deposits and limestone walls that if the water were now drawn away evidences of its previous presence would scarcely be observed. Only one cave—Tucker's Town—seems to show any mark of sea-level. In that cave the influence of the tide has been to retard the mural deposits along a 2 ft. zone. The general absence of this effect suggests recent change of level.

It seems significant for the theory of the origin of caves and, indirectly for the history of Bermuda, to emphasize that, if the

[1] Cf. Verrill, A. E., *Am. Journ. Sci.*, ser. IV, ix, 1900, p. 322.

fluctuating tide water is so ineffectual a solvent, it is unlikely to have been an effective agent in the origin of the Bermuda caves. The obvious conclusion is that the agent responsible for initiating the caverns was fresh water. The bottoms of the caves, therefore, mark the water table of the time, which would, in turn, approximate to sea-level in so small and so porous a land mass.

That caves are formed above the water table seems to be tacitly assumed in most discussions. But Weller [1] is the only writer who has attempted to analyse the relation between cave and water table. The whole problem of cave origin awaits systematic study and presentation.

The occurrence of stalactites and other deposits beneath sea-level has been cited as evidence of the submergence of the islands. The mere presence of sea water in the caves is more significant evidence of submergence, because it yields the means of estimating the amount of the change of sea-level.

Allowing for fallen fragments of the roof, the depth of sea water within the caves indicates that sea-level was previously 50 to 60 feet lower than at present. This is a minimum figure. To obtain the maximum figure the gradient of the water table of that time must be estimated. It is uncertain how far above sea-level the water table was when the area of the island was increased tenfold. Verrill [2] suggests the total change of level may have been 100 feet. Such a figure means that the water table as measured by the bottoms of the caves would have been 40 to 50 feet above sea-level. To the writer these figures seem too large. The minimum figures of 50 to 60 feet for the total change of level seem nearer to the truth.

Date and History of Cave Formation.

Solution effects of the cavern type are limited to the compact Walsingham limestone. The less compact limestones—the slightly cemented dune sands—show certain solution effects but apparently they are too porous to permit sufficient concentration of migrating surface water to form caverns.

Much of the Walsingham limestone is of aeolian origin, and similar to the later rocks in practically every respect except consolidation. In keeping with its marked compactness, the Walsingham is well jointed.

Since the effects of solution in the Walsingham rocks are of the cavern type and are controlled by jointing, the conclusion is inescapable that the consolidation of the Walsingham occurred before the time of origin of the caves. Previously, during the period of consolidation, the limestones seem to have been free from the effects of concentrated circulation of ground water. It is uncertain what the situation was during that time. The more recent dune limestones

[1] Weller, J. M., *Kentucky Geol. Surv.*, ser. IV, xxviii, 1927, p. 42 et seq.
[2] Verrill, A. E., *Am. Journ. Sci.*, ser. IV, ix, 1900, p. 318.

are becoming cemented by the general downward filtering of the rain-water, which leaches the upper layers and deposits the calcium carbonate among the grains of the lower layers. On the other hand, it is not impossible that the Walsingham was submerged and that lithifaction occurred beneath sea-level. The Walsingham is more compact than any of the later rocks. Microscopic study of thin sections may contribute the answer to this question.

It is doubtful if cave formation is as active now as in an earlier epoch. From observations it appears that stalactites are now being formed rapidly in most of the caves. This indicates that the ground water, in part at least, is depositing rather than dissolving. The height of the surface above the sea has diminished both because of weathering of the surface and because of the rise of sea-level. The soil blanket has increased in thickness, increasing correspondingly its capacity to retain water. Surface water, now passing downward through the soil, may well become saturated with mineral matter before it reaches bed-rock, and therefore be not as effective a solvent as the seepage of an earlier epoch when the soil was thinner. In a few places the overburden of encroaching dunes has added to the distance through which the ground water must percolate and has therefore increased its mineral content.

The age of the Walsingham limestone is either late Pliocene or early Pleistocene. The time required for the consolidation of that limestone was considerable and elapsed before the excavation of the caves. Thus a maximum limit for the age of the caves is established. It is difficult to determine a minimum limit, particularly for those parts of the caves which were excavated below present sea-level. Two kinds of evidence have been found which bear on this point. The first is typified by a condition found at the Shore-Hills Hotel quarry. Above the Walsingham limestone, in which occurs a small cave, may be found a prominent soil layer, called by Sayles[1] the Stokes soil. Portions of it have become intercalated in the cave deposits. This condition may be seen in other caves also, but not so clearly. Such soils have reached their present positions in some instances by washing through solution holes and sink holes in the roofs of the caves; by mechanical collapse of the ceilings in other cases. At other localities the Stokes soil is older than the later marine limestone as well as the other dune sands and soils. Since at the Shore-Hills Hotel quarry a succession of falls of the Stokes soil are, in turn, covered by stalagmitic deposits, considerable antiquity is suggested for the age of the caves.

A second and more positive kind of evidence was found at Stokes Point—the type locality for the Stokes soil. There fragments of cave deposits, and boulders of the Walsingham which show solution and deposition, were found in the Stokes soil. Similar fragments were found in the soil pits near the west end of the Causeway. Such

[1] Sayles, R. W., unpublished manuscript.

evidence suggests that considerable cave formation had taken place before the Stokes soil had reached its greatest thickness.

But that the solution at the minus 50 to 60 ft. level actually took place before Stokes time is not conclusively proved. The portions of the caves formed before Stokes time may have been deepened during a subsequent lowering of base-level. The shape of the caves was studied to try to find evidence of such change of level, but without positive results.

Sayles[1] tentatively places the Stokes soil equivalent to the first interglacial—Aftonian—epoch of the Pleistocene. If this correlation is correct, the evidence suggests strongly that caves were actively excavated during the first glacial advance, and that during this Nebraskan stage sea-level in Bermuda was 50 to 60 feet lower than at the present time.

On the Coral Genera *Endophyllum* Edwards and Haime and *Spongophyllum* Edwards and Haime.

By O. A. Jones, M.Sc., F.G.S., Emmanuel College, Cambridge.

(PLATE X.)

THE genera *Endophyllum* and *Spongophyllum* were founded by H. M. Edwards and J. Haime (1851, p. 393 and p. 425),[2] upon Devonian Corals from South Devonshire. Their descriptions of these (1851, pp. 394 and 425; 1853, pp. 233 and 242), though clear as far as they go, nevertheless leave room for further details, and their figures (1853, pl. lii, fig. 6; pl. liii, fig. 1; and pl. lvi, figs. 2, 2*a–e*) unfortunately do not include longitudinal sections of either of their two species of *Endophyllum*. Later workers on Devonian corals—C. Schlüter (1889, p. 50) and F. Frech (1885, p. 74; 1886, p. 87) have differed widely from the authors in their interpretation of the genera, and therefore a revision of the type-species is desirable.

This paper confines itself to the British species of the two genera, and considers only material from Devonshire. *Endophyllum bowerbanki* and *Spongophyllum sedgwicki* are interpreted upon neotypes (since the original material cannot be traced), but *Endophyllum abditum* upon the holotype supplemented by new material.

Genus Endophyllum Edwards and Haime, 1851, p. 393.

Genosyntypes :—

Endophyllum bowerbanki Edwards and Haime, 1851, p. 394; 1853, p. 233, pl. liii, fig. 1.

Devonian, Barton, near Torquay.

[1] Sayles, R. W., unpublished manuscript.

[2] See Bibliography, p. 90.

Endophyllum abditum Edwards and Haime, 1851, p. 394 ; 1853, p. 233, pl. lii, fig. 6.

Devonian, Beach, Teignmouth, near Torquay.

Genolectotype :—

E. bowerbanki. See C. Schlüter, 1889, p. 51.

Diagnosis.—Sub-phaceloid, cerioid or thamnastraeoid rugose corals in which the septa do not reach the periphery of the corallites but end as septal crests within the dissepimental tissue, and tend to break up peripherally into a meshwork of spine-like elements and structureless stereom. The tabulae are numerous and crowded, and are differentiated into an inner and an outer series. The dissepiments are for the most part large, and form in *E. abditum* a fairly wide peripheral zone, and in *E. bowerbanki* a still wider development of tissue connecting the corrallites.

Remarks.—The septal structure of *Endophyllum bowerbanki* recalls that of *Chonophyllum perfoliatum* Goldfuss MS. Edwards and Haime (1851, p. 405 ; 1854, p. 291), a Silurian coral from Gotland ; and also of a Devonian coral identified by Edwards and Haime (1851, p. 406 ; 1853, p. 235) with *C. perfoliatum*.

Neither the type of tabulae nor the character of the dissepiments are peculiar to the genus but are found independently in many coral lineages. Apart from the structure of the septa abovementioned which appears to be much more strongly developed in the thamnastraeoid species than in the sub-phaceloid or cerioid forms, the character which distinguishes the two species is the presence or absence of the divisional walls (epitheca). Forms intermediate between *E. bowerbanki* and *E. abditum* are nevertheless found.

It is not yet established whether the members of the *bowerbanki-abditum* series are mutations, i.e. variants in a vertical sense, or only varieties, i.e. variants in a horizontal sense.

The growth habit of *Endophyllum* varies considerably ; the same colony may be sub-phaceloid in one place and truly cerioid in another.

Endophyllum bowerbanki Edwards and Haime.

(Pl. X, Figs. 1, 2.)

Endophyllum bowerbanki H. M. Edwards and J. Haime, 1851, p. 394.
,, ,, ,, ,, ,, 1853, p. 233, pl. liii, fig. 1.
,, ,, C. Schlüter 1889, pp. 52–4, pl. v, figs. 1–3.

Diagnosis.—*Endophyllum* with strongly modified septa and without epitheca between the corallites.

Description.—The corallum of *E. bowerbanki* which is thamnastraeoid attained a large size, and museum specimens a foot or more in diameter are common. The form of the colony is generally flat and spreading. The corallites are typically united throughout by their dissepimental tissue without any traces of epithecal walls between the individuals.

The interior of the corallites is divisible into two areas, an inner one occupied by tabulae, and an outer one formed of dissepiments. The dissepimental tissue of adjacent corallites is continuous, but the septa of each individual terminate a short distance beyond the theca, and are not confluent with those of the neighbouring corallites. The major septa reach, or nearly reach, the axis, but the members of the minor cycle are short and do not extend very far inward into the intrathecal part of the coral. There are 30 to 35 major septa in large corallites measuring 3–4 cm. in diameter. The septa which are axially lamellar, split up peripherally into a vertical series of crests which rest on successive dissepimental platforms, and at the same time break into spicular elements [1] which are engulfed in stereom.

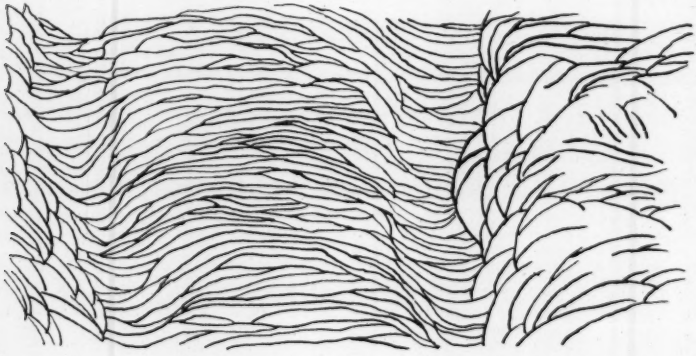

FIG. 1.—*Endophyllum bowerbanki* Ed. & H. (neotype). Diagram of longitudinal section, showing the two series of tabulae, the large dissepiments, and the theca. The greater part of the dissepiments on the left of the corallite, and all the septa including spines and crests are omitted. N.B.—The dissepimental tissue is much crushed and broken. × 3·75 approx.

Thus peripherally they appear dilated, indistinctly defined, and granular.

The tabulae are numerous and crowded, and consist of an inner series of complete or incomplete transverse plates, which, although nearly flat, are distally convex, and of an outer series occupying a relatively narrow zone, which curve sharply downwards and then as sharply upwards to meet the dissepiments. The dissepiments are mostly very large, and although they rise steeply at the theca assume a more or less horizontal position between the corallites. The inner wall or " theca ", formed by the upturned edges of the tabulae abutting against the dissepiments, is well marked, being usually reinforced to some degree by additional stereom.

[1] It is possible that Synapticulae, i.e. horizontal rods connecting septa, which authors have described in certain corals, may be a further development of the structure here noticed.

The intrathecal areas of the corallites are typically 2·5 to 3 cm. in diameter, whilst the distance between the axes of adjacent corals is from 3 to 4 cm.

Type Specimen.—The original specimens described by Edwards and Haime have not been traced. It is thus necessary to select, at least provisionally, a specimen as neotype, and British Museum specimen R. 1448 from the Upper Devonian, Rocky Valley, Torquay, is therefore chosen.

Description of neotype.—The specimen is a polished slab of coral roughly pentagonal in outline, and of a pink colour. It measures about 15 cm. in diameter and 2 cm. in thickness. The polished surface provides an excellent transverse section, displaying clearly the structure of the coral. A transverse section (R. 26295) has been cut from the under surface and two longitudinal sections (R. 26296) and (R. 26297) from one of the sides.

Remarks.—Edwards and Haime remark that the corallites are " more or less intimately united by rudimentary exterior walls and and irregular vesicular tissue ", and their figure shows such a wall limiting the corallites. The species was clearly established on a form intermediate between the distinctive thamnastraeoid *E. bowerbanki* and the cerioid *E. abditum* but agreeing more closely with the former than with the latter. For neotype a form has been chosen which is definitely thamnastraeoid.

Endophyllum abditum Edwards and Haime.

(Pl. X, Figs. 3, 4.)

Endophyllum abditum H. M. Edwards and J. Haime, 1851, p. 394.
" " " " " 1853, p. 233, pl. lii, fig. 6.

Diagnosis.—*Endophyllum* in which the septa are less modified than in *E. bowerbanki* and in which the corallites are defined by an epitheca.

Description.—The corallum is sub-phaceloid or cerioid. Typically the corallites are contiguous but sometimes are incompletely so having free rounded angles. (See Edwards and Haime, 1853, pl. lii, fig. 6.) The colonies grow to a large size. The internal structures of *Endophyllum abditum* do not differ in any essential way from those of *E. bowerbanki*. The septa divide peripherally into segments, the major septa are long, the minor are very short ; the tabulae consist of an inner and outer series, and the dissepiments are large.

The septa exhibit only slightly the peripheral modifications of *E. bowerbanki*. They almost reach the epitheca which is typically strongly developed and is serrated on its inner side by ridges representing the dissociated peripheral ends of the septa.

The dissepiments are steeply inclined and include both large and small arched plates.

Type Specimen.—Holotype. The coral figured by Edwards and Haime, 1853, pl. lii, fig. 6, now in Torquay Museum (Specimen $\frac{57}{7}$) ;

formerly in Dr. Robert Battersbdy's collection; from the Beach, Teignmouth.

Dr. Stanley Smith, who examined the specimen, has supplied the following particulars: "The holotype of *Endophyllum abditum* is a thin slab of coral, measuring 13 cm. × 10 cm. and is 2 cm. in thickness. The coral is of a light reddish grey colour, and has been cemented on to slate. The largest corallite is 5 cm. in diameter and has an intrathecal area of 3·5 cms.

"Edwards and Haime's figure although an excellent illustration of the species is not an accurate copy of the specimen. The artist has freely used his imagination in making the drawing and has restored those parts of the coral which are crushed or are obscure. The large corallite above mentioned is nevertheless accurately reproduced and this and certain other details noticed in the figure, made it possible to identify the specimen with certainty as the one actually figured."

Remarks.—Edwards and Haime state that in *E. abditum* there are 34 to 40 principal septa, but none of the corallites in their figure show more than 35 and the writer has found as few as 30.

Genus SPONGOPHYLLUM Edwards and Haime, 1851, p. 425.

Genotype (by monotypy). *Spongophyllum sedgwicki* Edwards and Haime, 1851, p. 425.

Devonian, Torquay.

Diagnosis.—Compound rugose corals which are typically cerioid but which may be sub-phaceloid or even phaceloid. The corallites are characterized by a wide extrathecal and a narrow intrathecal area. The dissepiments are very large; the tabulae are complete, horizontally disposed and the septa which may or may not extend to the epitheca, are normally thin, but in the earlier species may be strong.

Spongophyllum sedgwicki Edwards and Haime.

(For figures see Edwards and Haime, 1853, pl. liv, figs. 2*a–e*.)

Spongophyllum sedgwicki H. M. Edwards and J. Haime, 1851, p. 425.
,, ,, ,, ,, ,, 1853, p. 242, pl. liv, figs. 2, 2*a–e*.

Description.—Typically, the corallites are in complete lateral contiguity with their neighbours and are therefore prismatic and give rise to cerioid colonies; but sometimes they are only partly in contact and in such cases are sub-prismatic, their free sides or angles being rounded. The septa, which are usually thin and often somewhat wavy, may reach the wall or may end as crests against the dissepiments as in *Endophyllum*. There are 14 or 16 major septa and these reach or almost reach the axis. The minor septa are very short and may be represented merely by ridges on the inside of the epithecal wall. The tabulae are horizontal or distally concave,

widely separated and small. The dissepiments on the other hand are very large and form a single series of steeply inclined, strongly curved plates, but these are supplemented here and there by a few smaller plates.

Type Specimen.—Neotype. British Museum Specimen, R. 4999, Beckles Collection, from South Devonshire, is provisionally selected as neotype since none of Edwards and Haime's specimens has yet been traced. It is a dark coloured pebble 10·5 cm. long, 8·5 cm. wide, and 2·5 cm. thick with a polished upper surface which displays well the characters of the species. Two faces have been ground flat but these have not been polished. Sections R. 26 300 (transverse) and R. 26301 (longitudinal) have been recently prepared from one end of the specimen and the newly cut surface has been polished.

Remarks.—Edwards and Haime's figures afford excellent illustrations of the coral, but it may be pointed out that the longitudinal section—2*e*—is shown upside down.

Spongophyllum sedgwicki is usually cerioid but a few specimens are sub-phaceloid. The writer has examined one specimen (Whidborne Collection, Sedgwick Museum, Cambridge) which is almost phaceloid, but in this the septa appear to be even less strongly developed than they normally are, and it is possible that the specimen represents a distinct species.

Affinities of *Endophyllum* and *Spongophyllum* and Review of the Literature of these Genera.

The relationship of *Endophyllum* and *Spongophyllum* to each other and to other Devonian genera cannot be profitably discussed until the Devonian corals have been more thoroughly revised. Neither of the two genera have received much attention from later writers although they have been noticed and their structure and affinities have been considered by several.

Both the genera illustrate the "*Lonsdaleia*" trend, a fact to which, in the case of *Spongophyllum*, Edwards and Haime themselves draw attention. Apart from this and the fact that colonies of *Endophyllum abditum* and *Spongophyllum sedgwicki* are indefinitely sub-phaceloid or cerioid they possess little in common. One is a large form with specialized septa and fairly advanced tabulae, and the other a small form with very simple septa and tabulae.

Edwards and Haime, Dybowski (1874, p. 404) and C. Schlüter (1889, p. 54) did not regard *Endophyllum* and *Spongophyllum* as having very close relationship, in fact, these authors draw no comparisons between the genera; but Frech (1886, p. 87) merges *Spongophyllum* with *Endophyllum* as a synonym of the latter.

Edwards and Haime considered *Endophyllum* to be intermediate between *Cyathophyllum* and *Acervularia*; but this opinion has little meaning since these authors included Silurian, Devonian and

Carboniferous corals of various lineages in *Cyathophyllum* and included in *Acervularia* the Silurian *A. ananas* (the genotype of *Acervularia*) and cerioid forms of the Devonian genus *Phillipsastraea*. They state that " in *Acervularia* there is a well-developed epitheca which does not exist in *Endophyllum* ", but the statement is ambiguous, since *Endophyllum abditum* has been shown to have a strong epithecal wall.

Dybowski and Schlüter state that *Endophyllum* has no inner wall. It is true that in this genus there is no structure comparable to the inner wall in *Acervularia* and certain other corals, but it has, in common with all corals in which there is a peripheral investment of dissepimental tissue, a theca, i.e. the wall formed by the innermost dissepiments against which the tabulae abut—moreover the inner tabulae form a more or less well-defined central column.

The most recent views on *Spongophyllum* are those expressed by R. Wedekind (1925, pp. 49–52) who derives *Spongophyllum* along with *Neospongophyllum* Wedekind (1922, p. 10 ; 1925, p. 52), *Schizophyllum* Wedekind (1925, p. 59), and *Stringophyllum* Wedekind (1922, p. 8 ; 1925, p. 64), from *Loipophyllum* Wedekind (1925, p. 55). These genera all show in a more or less advanced degree the Lonsdaloid trend but their general structure—wide tabulate areas, numerous tabulae and strong development of septal crests on successive dissepimental floors—are reminiscent of *Endophyllum* rather than *Spongophyllum*.

Wedekind does not state whether he interprets *Spongophyllum* upon topoty or upon Eifel material and he gives no figures of the genus. It is therefore uncertain whether he has in mind Edwards and Haime's form or another coral.

The writer wishes to express his thanks to Dr. W. D. Lang for the loan of material from the British Museum, to Dr. Stanley Smith for a careful revision of the paper, for supplying the description of the holotype of *E. abditum* and for calling his attention to the similarity of the septa of *Endophyllum* and *Chonophyllum perfoliatum*, and to Dr. G. L. Elles and Dr. H. D. Thomas for reading the manuscript.

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FIG. 1. × 2.

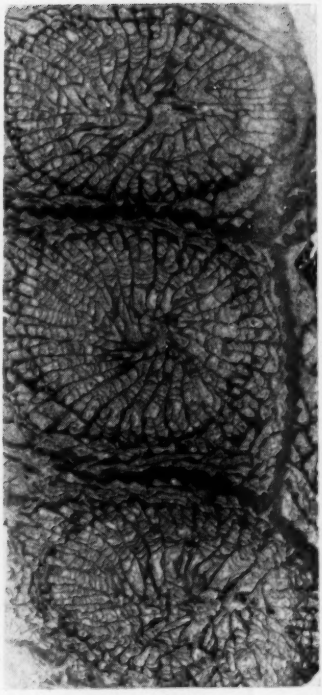
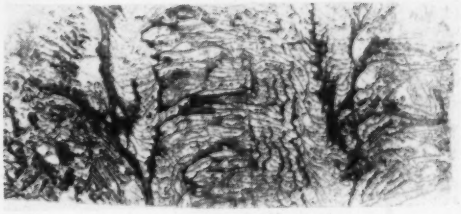


FIG. 3. × 2.

FIG. 2. × 2.



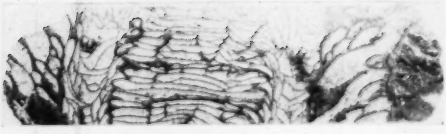


FIG 4. × 2.

ENDOPHYLLUM BOWERBANKI AND *ARDITUM*.

To face p. 91

1889. Schlüter C. "Anthozoen des rheinischen Mittel-Devon." *Abhandl. zur geol. Specialkarte von Preus. und den Thuring. Staaten.*, Bd. viii, Heft 4, pp. viii–1–207, pls. i–xvi.

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1925. Wedekind, R. "Das Mitteldevon der Eifel," ii Teil. *Materialien zur Kenntnis des mittleren Mitteldevon. Schriften der Gesell. zur Beforderung der Naturw. zu Marburg.*, Vierzehnter Bd., Viertes Heft., pp. vii, and 1–85, figures and tables.

EXPLANATION OF PLATE X.

Fig. 1.—*Endophyllum bowerbanki*, cross section of neotype. × 2.

Fig. 2.—*E. bowerbanki*; longitudinal section of one corallite of neotype. × 2.

Fig. 3.—*E. abditum*; cross section of a specimen from South Devon (British Museum R. 26300) × 2.

Fig. 4.—*E. abditum*; longitudinal section of the same (British Museum R. 26301). × 2.

REVIEWS.

Rhodesian Man and Associated Remains. By various authors. 76 pp., 5 pls., 23 figs. British Museum (Natural History), London, 1928. 12*s.* 6*d.*

THE British Museum (Natural History) monograph on the famous Rhodesian skull has made its welcome but somewhat belated appearance. Sir Arthur Smith Woodward unfortunately was unable to write the memoir, so it was entrusted to Mr. W. P. Pycraft. The general character of this remarkable cranium is fairly well known, but measurements and detailed descriptions and comparisons are here presented for the first time. Mainly on the basis of his interpretation of the acetabular region of the broken pelvis, Mr. Pycraft has erected a new genus (*Cyphanthropus*) for Rhodesian man, but Professor W. E. Le Gros Clark contends that it corresponds quite well with the acetabulum of a modern human pelvis (*Man*, 1928, No. 149). Most anthropologists are agreed that the creature belonged to the genus *Homo*: this is also the view of Professor G. Elliot Smith, who gives a description of the endocranial cast. He says, "It is this defective development of certain areas that differentiates the Rhodesian cast from that of the Neanderthal series, and, with various cranial characters, justifies the creation of a new species of a more primitive rank." The few associated stone implements are briefly described by Mr. Reginald A. Smith; the evidence is meagre, but there seems to be an ill-defined Mousterian character about them. Almost all the animal bones from Broken Hill belong to existing local species; Mr. A. Tindell Hopwood describes a new species of Serval cat from a broken mandible and some bones of an extinct two-horned rhinoceros were found. He says, "It is practically impossible at present to estimate the age of African cave deposits by means of the fossil mammals. The fact

that two extinct forms are known proves nothing. It is becoming ever more apparent that the mammal-bearing horizons of Central Africa are not comparable in age with those of Europe, and that in dealing with them it is useless to apply European standards. On the evidence of the associated mammalian fauna there is no reason to suppose that the human remains are of anything but recent date." In addition to an enormous number of animal bones parts of at least three human skeletons were found. The descriptions of the finding of the remains are somewhat contradictory and obscure. Dr. F. A. Bather sums up the evidence by saying, " The position of the skull (and skeleton) at the very end of the assumed former cave, as well as the coating of stalagmite by which its mode of preservation was differentiated from that of all other bones in the cave-filling, suggests that, whatever the age of the general fossil fauna of the cave, the age of the skull is appreciably greater."

A. C. H.

ASSIMILATION AND PETROGENESIS: SEPARATION OF ORES FROM MAGMAS. By JOHN STANSFIELD. pp. 197, plates 30. Valley Publishing Co., Urbana, Illinois, 1928. Price $3·50.

THIS volume presents the results of extended experiments in which in the words of the author " a chosen series of ten igneous rocks representing common magmatic products ranging from granite at the acid end of the series to peridotite at the ultrabasic end of the series was to be caused to assimilate known amounts of carefully chosen materials representing pure sediments." The assimilated material included calcite, kaolin, and quartz, and the experiments were extended to include mixtures of igneous rocks with iron ores, sulphides, carbonates, bauxite, and even tremolite-schist. The finely ground mixtures were heated to temperatures from 1230 to 1600 degrees C., maintained at these temperatures for some hours, and then slowly cooled. The first two chapters are of the nature of a summary of present day views on differentiation and the rôle accorded to assimilation in petrogenesis. The remainder of the book is devoted to the results of the author's experiments.

A large number of minerals is recorded from the fusions. They include åkermanite, melilite, monticellite, riebeckite, and perovskite formed by assimilation of calcite; cordierite, plagioclase, sillimanite, and spinel by assimilation of kaolin; augite, olivine, and garnet by assimilation of magnesite; enstatite from assimilation of iron-bearing minerals. Some of the determinations seem not free from doubt.

The fusion of kimberlite and magnesite in the proportion 1 : 1 is stated to have yielded a product consisting of 60% olivine and 40% garnet. As this supposed garnet must of necessity be rich in MgO, this is the first record of the production of pyrope, which it is customary to believe is stable only under high pressures. The

frequent record of enstatite among the melts is in itself suspicious, and one is tempted to inquire whether this mineral has not been confused with forsterite. The riebeckite and åkermanite recorded as the sole products of fusion of minette with calcite can scarcely be the normal minerals, when the minette itself contains 19·5 per cent Al_2O_3. A product consisting of 80 per cent andalusite (?) is reported from a fusion of minette and bauxite. There are other anomalies. The recorded sillimanite is doubtless mullite. Unquestionably the most interesting fusions are those in which calcite is the assimilated material, producing åkermanite, perovskite, monticellite, and melilite. These fusions are suggestive in the light of the occurrence of these minerals in some igneous rocks at limestone contacts.

As, however, in the experiments an unlimited supply of heat has been available, no valid analogies can be drawn with natural rocks where no such superheat can be postulated, and we can scarcely conclude with the author that "the assimilation hypothesis of Daly regarding the origin of many igneous rock types is seen to be supported in a general way by the results of the experiments described above."

The reviewer cannot but conclude that experimental work of this kind belongs more properly to the period of the last century when Fouqué, Lévy, Morosewicz, and others were carrying out their pioneer work on rock-synthesis, before the present methods of precision were available for petrogenetic study. Interesting as the experiments are, they cannot be said to have materially advanced our knowledge of the subject which forms the title of the book. The photomicrographs which accompany the descriptions excellently illustrate the products of the fusions. The volume is dedicated to Professor R. A. Daly.

REPORTS AND PROCEEDINGS.

Mineralogical Society.

6th November, 1927.

Mr. F. A. Bannister: "The so-called 'thermokalite' and the existence of sodium bicarbonate as a mineral."

The composition of a large collection of saline incrustations collected by Dr. Johnston-Lavis about 1889 has been investigated. He labelled them "thermokalite", but they are found to be a mixture of trona, thermonatrite, thenardite, and free sodium bicarbonate; no potassium salts are present. The name nahcolite is proposed for naturally occurring sodium bicarbonate. These incrustations were found lining the walls of a cuniculus near the Stufe di Nerone, Baia, Naples, Italy; their mode of occurrence is discussed from a physical-chemical point of view.

Dr. W. A. Wooster: "The piezo-electric effect of diamond." The effect has been investigated by a delicate method using

magnetic attraction to apply pressure to the diamond. The result shows that the effect, if it exists, is less than $\frac{1}{300}$th of the effect observed in quartz cut perpendicular to the electric axis.

Mr. J. D. Bernal and Mrs. Wooster showed X-ray photographs of the arkansite variety of brookite indicating that the space-group is Q_h^{15}. An explanation was offered of how A. Schröder's observations did not lead to this result.

Mr. F. N. Ashcroft exhibited specimens of minerals collected recently in Switzerland, together with photographs of the localities represented.

Glasgow Geological Society.

8th November, 1928.

"The Dykes and Associated Intrusions of the Island of Bute." By H. J. W. Brown, M.Sc., A.K.C.

Four sets of dykes and accompanying intrusions were distinguished: Devonian, Carboniferous, Permo-Carboniferous, and Tertiary. A dyke of mica-lamprophyre of north-easterly trend appears to be the sole representative of Devonian igneous activity. The Carboniferous dykes, however, are very numerous. They are connected with the Lower Carboniferous vulcanicity of the south end of Bute, and have a general E.N.E. trend. Petrographically they include basalts of Markle, Markle-Dunsapie, and mugearitic types. No Carboniferous dykes are found north of the Highland Boundary Fault which bisects the island. Two large and continuous quartz-dolerite dykes of the usual characters represent the Permo-Carboniferous. They cross the island from east to west in the region south of Rothesay Bay.

Tertiary intrusions are by far the most numerous in Bute. They include two large sills which have been described by Dr. W. R. Smellie; the great composite sill of hypersthene-dolerite and quartz-porphyry (closely resembling the Arran sills at Bennan and Drumadoon), which cuts a large sill of crinanite. Smellie regarded this sill as of Permo-Carboniferous age, but petrographically it is identical with the crinanite sills of the south-eastern quadrant of Arran. The dykes are very numerous, and are scattered throughout the island, although less numerous north of the Highland Boundary Fault than they are to the south of it. Tholeiites of various types constitute the vast majority of the dykes, only two examples of the contrasted crinanite type having been found. Two new analyses have been made of the tholeiites, by Mr. W. H. Herdsman, of Glasgow, and these are in good agreement with published analyses of Mull, Arran, and mainland examples. North of the Highland Boundary Fault the trend of the Tertiary dykes is mainly N.N.W., although they range from N.W. to N.N.E. South of the Fault the trend is mainly N. to S., and at the south end of the

island some of the dykes run to the N.E. Hence there is evidence of a bending of the Bute tholeiite dykes towards the south, a tendency that is also found in Arran.

"Notes on the Preparation of Rock Sections for Microscopical Examination." By P. J. Robinson, A.M.Inst.C.E.

A chip of rock about $1\frac{1}{8}$ in. square is ground by hand on one face in the usual manner. The coarse grinding is carried out on a steel plate with No. 60 grit carborundum and water, followed by grinding on a zinc plate with No. 150 grit carborundum. The fine grinding is carried out on three pieces of plate glass charged respectively with FF carborundum, 600 grit grade "M" carborundum, and Swift's No. 8 "Quartz Wedge" emery. The lubricant used on these glass plates is a mixture of water 75 parts and glycerine 25 parts. In order that a harder and more tenacious cement than Canada balsam may be used, the chip, instead of being attached to a standard microscopical slip, is cemented to a plate glass holder about $1\frac{3}{4}$ in. square and ground to finished thickness thereon. The cement used consists of three parts by weight of wax-free shellac, and one part of natural Canada balsam, dissolved to the thickness of treacle in a mixture of two parts chloroform and one part absolute alcohol. The wax-free shellac is prepared by dissolving flake orange shellac in 98 per cent alcohol, filtering through a quick filtering paper and evaporating off the solvent on a water bath until a pliable solid results on cooling. Instead of the cement alone being cooked on a hot plate till the required degree of hardness is obtained and the chip then added and pressed down, the chip is placed on the raw cement and cooked along with it. This in effect is equivalent to boiling the chip in the cement and has obvious advantages. The grinding down of the chip to the required thickness is carried out successively on the plates and with the grades of abrasives previously mentioned. In the ultimate stage, if the section begins to break away at the edges due to its having become slightly convex, the holder plate is laid section up on the table and localised grinding carried out with a short length of glass rod about $\frac{1}{2}$ in. diameter which has one end ground to a flat.

After completion of the grinding, a small block of Plaster of Paris about 1 in. $\times$ $1\frac{1}{4}$ in. $\times$ $\frac{5}{8}$ in. deep having a perfectly flat bottom face is cemented on to and over the section with gum-plaster cement. This cement is made by mixing a small quantity of the finest dental Plaster of Paris to a smooth, stiff paste with gum arabic mucilage compounded to the following formula :—

gum arabic	45 gms.
white sugar	5 gms.
glycerine	2 c.c.
water	50 c.c.

The plaster block must be of such a size and so placed on the section that the gum-plaster joint is in contact either with the section or the surrounding film of shellac-balsam cement.